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IMPACT OF PESTICIDE APPLICATION ON PHYSICO-CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF SOIL: A STUDY OF SRI GANGANAGAR DISTRICT

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ABSTRACT

The widespread use of chemical pesticides in modern agriculture has raised serious concerns regarding their long-term impact on soil health and sustainability. The present study evaluates the influence of pesticide application on the physico-chemical and biological characteristics of soil in Sri Ganganagar district of Rajasthan. Soil samples were collected using a grid sampling method from pesticide-treated fields and control fields without pesticide application. The samples were analyzed for key physico-chemical parameters such as pH, electrical conductivity (EC), bulk density, alkalinity, cation exchange capacity (CEC), total organic carbon (TOC), nitrogen, and phosphorus. Biological parameters including microbial population, soil fauna, enzyme activities (amylase, cellulase, dehydrogenase, phosphatase, and urease), and carbon dioxide (CO_2) evolution were also assessed.

The results indicate that pesticide-treated soils exhibit increased pH, EC, alkalinity, and bulk density, while TOC, nitrogen, and CEC show a declining trend. Biological analysis revealed a significant reduction in microbial population, enzyme activity, and CO_2 evolution. Statistical analysis confirmed that these differences are significant ($p < 0.05$). The study concludes that pesticide application leads to multidimensional soil degradation and emphasizes the need for sustainable agricultural practices.

Keywords: Soil Health, Pesticides, Physico-Chemical Properties, Soil Microbial Activity, Enzyme Activity, CO_2 Evolution, Sustainable Agriculture

INTRODUCTION

Agriculture occupies a central position in the Indian economy, not only as a primary source of livelihood for a large proportion of the population but also as a key contributor to food security and rural development. With the increasing demand for higher agricultural productivity, the adoption of modern farming practices has become inevitable. Among these practices, the application of chemical pesticides has emerged as a significant tool for controlling pests, diseases, and weeds, thereby enhancing crop yield and quality. Pesticides such as insecticides, herbicides, and fungicides are widely used to protect crops from biotic stresses, ensuring stable agricultural production. However, while their short-

term benefits in improving productivity are undeniable, their long-term consequences on soil health and environmental sustainability have become a matter of serious concern.

Soil is not merely a physical medium for plant growth; it is a complex and dynamic living system that plays a vital role in maintaining ecological balance. It performs essential functions such as nutrient cycling, organic matter decomposition, water retention, filtration of pollutants, and providing habitat for a diverse range of microorganisms. The physico-chemical properties of soil, including pH, electrical conductivity, bulk density, cation exchange capacity, and nutrient content, determine its fertility and productivity. Simultaneously, biological components such as microbial populations, soil fauna, and enzyme activities are crucial for maintaining soil vitality and supporting biochemical processes. Any disturbance in these interconnected properties can disrupt soil functioning and lead to gradual degradation.

The excessive and indiscriminate use of pesticides has been identified as one of the major factors contributing to soil degradation. Pesticides, when applied repeatedly over time, tend to accumulate in the soil, altering its chemical composition and affecting its physical structure. They can increase soil alkalinity and salinity, reduce organic matter content, and impair nutrient availability. More importantly, pesticides exert toxic effects on beneficial soil microorganisms, leading to a decline in microbial diversity and activity. Since microorganisms are responsible for key processes such as nitrogen fixation, decomposition, and enzyme production, their suppression results in reduced soil fertility and impaired ecosystem functioning. Additionally, pesticide residues may persist in the soil for extended periods, causing long-term contamination and posing risks to both environmental and human health.

Sri Ganganagar district of Rajasthan presents a particularly relevant context for studying these impacts. Often referred to as the "food basket of Rajasthan," the district is characterized by intensive agricultural practices supported by an extensive irrigation network, primarily through the Indira Gandhi Canal system. The region has witnessed a significant increase in the cultivation of crops such as wheat, cotton, and mustard, which require substantial use of agrochemicals, including pesticides. Over the years, the continuous application of these chemicals has raised concerns regarding soil quality deterioration, declining productivity, and ecological imbalance. Farmers in the region have increasingly reported issues such as reduced soil fertility, increased input requirements, and diminishing returns, which may be linked to the degradation of soil properties.

In this context, it becomes essential to scientifically evaluate the extent to which pesticide application has influenced soil characteristics in Sri Ganganagar district. The present study is therefore designed to assess the modifications in both physico-chemical and biological properties of soil due to pesticide usage. By comparing pesticide-treated soils with control soils, the study aims to identify specific changes in parameters such as pH, electrical conductivity, organic carbon, nutrient content, microbial population, enzyme activities, and carbon dioxide evolution. Such an assessment is crucial for understanding the underlying mechanisms of soil degradation and for providing empirical evidence to support sustainable soil management practices.

Furthermore, the findings of this study are expected to contribute to the development of environmentally sound agricultural strategies, such as integrated pest management (IPM), reduced chemical dependency, and the adoption of organic alternatives. By highlighting the adverse impacts of excessive pesticide use, the study seeks to promote awareness among farmers, policymakers, and researchers regarding the importance of maintaining soil health for long-term agricultural sustainability. Ultimately, preserving soil quality is not only essential for ensuring crop productivity but also for safeguarding ecological balance and supporting future generations.

REVIEW OF LITERATURE

A substantial body of scientific literature has consistently highlighted the adverse effects of pesticide application on soil health, particularly with respect to its biological and biochemical functioning. Bending et al. (2001) demonstrated that the application of pesticides significantly alters the structure and composition of soil microbial communities, leading to a shift in microbial diversity and a reduction in beneficial microorganisms. Such alterations can disrupt essential ecological processes, including nutrient cycling and organic matter decomposition. Similarly, Chowdhury et al. (2008) reported that pesticide exposure results in a marked decline in microbial activity and soil enzyme functions, which are critical indicators of soil fertility and biological health. The inhibition of enzymes

such as dehydrogenase and phosphatase reflects the suppression of microbial metabolism and nutrient transformation processes.

Further emphasizing the biochemical implications, Megharaj et al. (2010) noted that pesticides interfere with soil biochemical processes by affecting microbial respiration and enzymatic reactions, ultimately leading to reduced soil productivity. Kandeler et al. (1996) highlighted that soil enzyme activities are highly sensitive to external chemical disturbances, including pesticide application, and can serve as early indicators of soil degradation. Their study revealed that even low concentrations of pesticides can significantly inhibit enzyme activity, thereby affecting nutrient mineralization and soil biochemical balance.

In addition to biological impacts, Arias-Estévez et al. (2008) provided important insights into the environmental behavior of pesticides in soil systems. Their work focused on the persistence, mobility, and degradation pathways of pesticides, demonstrating that many compounds remain in the soil for extended periods and can leach into groundwater, thereby posing risks to both soil and water quality. The accumulation and persistence of pesticide residues contribute to long-term contamination and exacerbate their negative effects on soil properties.

Despite the availability of extensive global and national studies on the impact of pesticides on soil health, there remains a significant gap in region-specific research, particularly in the context of Sri Ganganagar district of Rajasthan. This region, characterized by intensive agricultural practices and heavy reliance on chemical inputs, presents unique agro-climatic and soil conditions that may influence the behavior and impact of pesticides. Therefore, there is a critical need for localized studies to assess the extent of soil degradation and to generate empirical data that can inform sustainable agricultural practices in the region.

MATERIALS AND METHODS

The present study was conducted to evaluate the impact of pesticide application on the physico-chemical and biological characteristics of soil in agricultural fields of Sri Ganganagar district, Rajasthan. A systematic and scientific methodology was adopted to ensure accuracy, reliability, and reproducibility of results.

Study Area

The study was carried out in Sri Ganganagar district, located in the northwestern part of Rajasthan, India. The district is characterized by a semi-arid climate, with hot summers and moderate winters. The region is predominantly agricultural, supported by extensive irrigation from the Indira Gandhi Canal system. The soils of the region are mainly alluvial in nature, suitable for the cultivation of crops such as wheat, cotton, mustard, and guar. Due to intensive farming practices, the area experiences high usage of chemical inputs, particularly pesticides, making it an ideal location for assessing their impact on soil properties.

Research Design

A comparative research design was adopted in the present study to evaluate the differences between pesticide-treated soils and untreated (control) soils. The study focused on identifying changes in both physico-chemical and biological parameters due to pesticide application. Control samples were collected from fields where pesticide usage was minimal or absent, providing a baseline for comparison. This design allowed for a clear understanding of the extent to which pesticide application influences soil characteristics.

Sampling Design and Collection of Soil Samples

The study area was divided into multiple grids to ensure representative sampling across different agricultural fields. A grid sampling method was employed to systematically collect soil samples from both pesticide-treated and control sites. Within each grid, soil samples were collected from a depth of 0–15 cm, which represents the active root zone and is most affected by pesticide application.

Multiple sub-samples were collected from each grid and mixed to form a composite sample, ensuring homogeneity and reducing variability. The collected soil samples were placed in clean polyethylene bags, properly labeled, and transported to the laboratory for analysis. Before analysis, samples were air-dried, sieved through a 2 mm sieve, and stored under appropriate conditions.

Parameters of Study

The study included a comprehensive analysis of soil characteristics, categorized into physico-chemical and biological parameters.

Physico-Chemical Parameters

The following physico-chemical properties of soil were analyzed:

* Soil Colour: Determined visually using standard soil color charts.
* Bulk Density: Measured using the core method to assess soil compaction.
* Soil Texture: Determined by particle size distribution using the hydrometer method.
* pH: Measured using a digital pH meter in soil-water suspension.
* Electrical Conductivity (EC): Determined using an EC meter to assess salinity.
* Alkalinity: Measured through titration methods.
* Cation Exchange Capacity (CEC): Determined using ammonium acetate method.
* Total Organic Carbon (TOC): Estimated using Walkley and Black method.
* Total Kjeldahl Nitrogen (TKN): Determined using Kjeldahl digestion method.
* Available Phosphorus: Measured using Olsen's method.
* Total Phosphorus: Determined using standard digestion techniques.

Biological Parameters

Biological characteristics of soil were assessed to evaluate soil health:

* Microbial Population: Estimated using serial dilution and plate count method.
* Soil Fauna: Observed qualitatively through field assessment and laboratory examination.

Soil Enzyme Activities

Soil enzyme activities were analyzed as indicators of biochemical processes:

* Amylase Activity: Measured using starch hydrolysis method.
* Cellulase Activity: Determined using cellulose decomposition assay.
* Dehydrogenase Activity: Measured as an indicator of microbial respiration.
* Phosphatase Activity: Assessed using p-nitrophenyl phosphate method.
* Urease Activity: Determined using urea hydrolysis method.

Carbon Dioxide (CO_2) Evolution

CO_2 evolution was measured to assess microbial respiration and soil biological activity. Soil samples were incubated under controlled conditions, and CO_2 released was quantified using standard titration methods.

Laboratory Analysis

All analyses were carried out using standard procedures and protocols as recommended in soil science literature. Proper calibration of instruments and quality control measures were ensured throughout the experimental process to maintain accuracy and reliability of results.

Statistical Analysis

The collected data were statistically analyzed using appropriate tools to interpret the results. Descriptive statistics such as mean and standard deviation were used to summarize the data. Inferential statistical tests, including t-test and chi-square test, were applied to determine the significance of differences between treated and control soils. Correlation analysis was also performed to examine the relationship between pesticide application and soil parameters. Statistical significance was considered at $p < 0.05$ and $p < 0.01$ levels.

RESULTS AND DISCUSSION

The results of the present study provide a comprehensive understanding of the impact of pesticide application on the physico-chemical and biological characteristics of soil in Sri Ganganagar district. The findings have been analyzed by comparing pesticide-treated soils with control soils, and the results are presented in tabular form along with detailed interpretation.

Physico-Chemical Characteristics of Soil

Table - 1: Physico-Chemical Properties of Soil

Parameter	Treated Soil	Control Soil	% Change
pH	8.25	7.65	+7.8%
EC (dS/m)	1.85	1.20	+54.1%
Bulk Density (g/cm³)	1.45	1.30	+11.5%
Alkalinity (mg/kg)	323	252	+28.2%
CEC (cmol/kg)	12.26	13.90	-11.8%
TOC (%)	0.44	0.60	-26.7%
Nitrogen (mg/kg)	207	275	-24.7%
Available Phosphorus (mg/kg)	19.0	15.5	+22.5%

Interpretation

The data clearly demonstrate that pesticide application has significantly altered the physico-chemical properties of soil. The pH of treated soils increased from 7.65 in control samples to 8.25, indicating a shift toward alkalinity. This increase in pH can adversely affect nutrient availability, particularly micronutrients such as iron and zinc, thereby reducing soil fertility. The rise in electrical conductivity (EC) from 1.20 to 1.85 dS/m reflects an increase in soluble salts due to pesticide accumulation, which may lead to salinity stress in crops.

Bulk density showed an increase of approximately 11.5%, suggesting soil compaction. Compacted soils have reduced pore space, which negatively affects water infiltration, aeration, and root penetration. Similarly, alkalinity increased significantly, indicating chemical imbalance caused by repeated pesticide applications.

In contrast, important fertility indicators such as cation exchange capacity (CEC), total organic carbon (TOC), and nitrogen content decreased substantially in treated soils. The reduction in TOC (26.7%) indicates loss of organic matter, which is crucial for maintaining soil structure and nutrient supply. The decline in nitrogen further suggests disruption of nitrogen cycling processes, likely due to reduced microbial activity.

Interestingly, available phosphorus showed an increase in treated soils. This may be attributed to reduced microbial uptake and mineralization processes, leading to accumulation of phosphorus in the soil. Overall, the results indicate that pesticide application leads to chemical degradation of soil, affecting both nutrient balance and physical structure.

Biological Characteristics of Soil

Table - 2: Biological Characteristics of Soil

Parameter	Treated Soil	Control Soil	% Change
Microbial Population (CFU ×10⁶/g)	3.15	5.70	-44.7%
Soil Fauna	Low	High	Decreased

Interpretation

The biological analysis reveals a significant decline in microbial population in pesticide-treated soils, with a reduction of nearly 45% compared to control soils. Soil microorganisms play a vital role in nutrient cycling, decomposition of organic matter, and maintenance of soil structure. The observed decline indicates that pesticides exert toxic effects on beneficial microorganisms, thereby disrupting soil ecological balance.

The presence of soil fauna, such as earthworms and insects, was also found to be reduced in treated soils. These organisms contribute to soil aeration, organic matter decomposition, and nutrient recycling. Their decline further indicates deterioration of soil biological health.

The reduction in both microbial population and soil fauna suggests that pesticide application adversely affects soil biodiversity, leading to impaired soil functioning and reduced agricultural productivity.

Soil Enzyme Activities

Table - 3: Soil Enzyme Activities

Enzyme	Treated Soil	Control Soil	% Change
Amylase	12.0	19.5	-38.5%
Cellulase	10.0	18.0	-44.4%
Dehydrogenase	21.5	36.5	-41.1%
Phosphatase	15.0	25.0	-40.0%
Urease	18.75	30.75	-39.0%

Interpretation

Soil enzyme activities showed a consistent decline in pesticide-treated soils. Enzymes are biological catalysts that facilitate essential biochemical processes in soil. Amylase and cellulase are involved in the breakdown of organic matter, while dehydrogenase is an indicator of overall microbial activity. Phosphatase and urease play key roles in phosphorus and nitrogen cycling, respectively.

The observed reduction in enzyme activities indicates inhibition of microbial metabolism and biochemical processes due to pesticide toxicity. This decline suggests that pesticide application disrupts nutrient cycling, reduces soil fertility, and affects overall soil health. The results are consistent with previous studies that have reported negative effects of pesticides on soil enzymatic activity.

Carbon Dioxide (CO_2) Evolution

Table - 4: CO_2 Evolution

Condition	CO_2 Evolution (mg/kg/day)
Control Soil	34
Low Pesticide Dose	28
Medium Dose	22
High Dose	18

Interpretation

CO_2 evolution, which serves as an indicator of microbial respiration, showed a decreasing trend with increasing pesticide concentration. The control soil exhibited the highest CO_2 evolution (34 mg/kg/day), while the high pesticide dose resulted in the lowest value (18 mg/kg/day).

This decline indicates that pesticide application suppresses microbial respiration and metabolic activity. Reduced CO_2 evolution reflects lower microbial activity and diminished decomposition of organic matter. This further confirms that pesticides negatively affect soil biological processes and contribute to soil degradation.

The overall analysis clearly indicates that pesticide application has a significant negative impact on soil health. The physico-chemical properties of soil were altered, with increased alkalinity, salinity, and compaction, along with decreased organic carbon and nutrient content. Biological characteristics, including microbial population and soil fauna, were adversely affected, leading to reduced biodiversity.

Furthermore, enzyme activities and CO_2 evolution showed a consistent decline, indicating disruption of biochemical processes and microbial metabolism. These findings suggest that pesticide application not only affects individual soil parameters but also leads to an integrated degradation of soil ecosystem functions.

The results are in agreement with previous studies by Bending et al. (2001), Chowdhury et al. (2008), and Megharaj et al. (2010), which reported similar negative impacts of pesticides on soil health. The statistical analysis further confirms that these changes are significant, highlighting the strong relationship between pesticide use and soil degradation.

CONCLUSION

The present study provides a comprehensive assessment of the impact of pesticide application on the physico-chemical and biological characteristics of soil in the agricultural fields of Sri Ganganagar district. The findings clearly demonstrate that the continuous and excessive use of pesticides has led to significant alterations in soil properties, resulting in overall soil degradation and reduced fertility.

From a physico-chemical perspective, pesticide-treated soils exhibited increased pH, electrical conductivity, alkalinity, and bulk density, indicating chemical imbalance, salinity buildup, and soil compaction. These changes adversely affect soil structure, water movement, and nutrient availability. At the same time, essential fertility indicators such as total organic carbon, nitrogen content, and cation exchange capacity showed a declining trend, reflecting the deterioration of soil nutrient status and reduced capacity for nutrient retention. Although an increase in available phosphorus was observed, it does not necessarily indicate improved soil fertility, as it may be associated with reduced microbial uptake and impaired nutrient cycling processes.

The biological characteristics of soil were found to be significantly affected by pesticide application. A substantial decline in microbial population and soil fauna was observed in treated soils, indicating the toxic effects of pesticides on soil biodiversity. Since soil microorganisms and fauna play a crucial role in maintaining soil health through decomposition, nutrient cycling, and soil structure formation, their reduction leads to impaired soil functioning and ecological imbalance.

Furthermore, soil enzyme activities—including amylase, cellulase, dehydrogenase, phosphatase, and urease—showed a consistent and significant decline in pesticide-treated soils. These enzymes are essential for various biochemical processes, and their inhibition reflects reduced microbial activity and disrupted nutrient transformations. The analysis of carbon dioxide (CO_2) evolution further supported these findings, as treated soils exhibited lower CO_2 release, indicating suppressed microbial respiration and metabolic activity.

The statistical analysis confirmed that the observed differences between pesticide-treated and control soils were significant, thereby establishing a strong relationship between pesticide application and soil degradation. The rejection of null hypotheses and acceptance of alternative hypotheses further validate the impact of pesticides on soil characteristics.

In conclusion, the study highlights that pesticide application has a multidimensional negative effect on soil health, affecting its physical structure, chemical composition, and biological functioning. These changes not only reduce soil fertility and productivity but also pose long-term risks to environmental sustainability. Therefore, it is imperative to adopt sustainable agricultural practices such as integrated pest management (IPM), reduced chemical dependency, and increased use of organic inputs to restore and maintain soil health. The findings of this study serve as an important scientific basis for policymakers, researchers, and farmers to promote environmentally responsible agricultural practices and ensure the long-term sustainability of soil resources.

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