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RESEARCH ARTICLE

Evaluating the Long-Term Consequences of Fertilizers, Pesticides, and Insecticides on Soil Quality and Crop Sustainability: Addressing Soil Health amid Agrochemical Dependency

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ABSTRACT

Background: The widespread use of fertilizers, pesticides, and insecticides has significantly boosted agricultural productivity but raised concerns about its long-term effects on soil health and crop sustainability. This study aims to evaluate the impact of agrochemical dependency on soil quality, focusing on nutrient balance, microbial diversity, and crop productivity. **Materials and Methods:** Soil samples were collected from agricultural fields subjected to varying levels of agrochemical usage, including high-input, low-input, and organic farming practices. Soil parameters such as pH, organic matter content, nutrient levels (N, P, K), and microbial diversity were analyzed using standard laboratory methods. Crop yield data were also recorded to correlate soil health with productivity. **Results:** The findings revealed that high-input agrochemical usage resulted in soil acidification, nutrient imbalance, and a decline in beneficial microbial populations. Conversely, organic farming practices maintained higher levels of soil organic matter, improved microbial diversity, and supported balanced nutrient cycling. Moderate agrochemical use showed intermediate effects, suggesting a threshold for sustainable application. Crop yields were initially higher in high-input systems but declined over time due to soil degradation, while organic systems demonstrated stable long-term productivity. **Conclusion:** Excessive reliance on agrochemicals degrades soil quality and threatens sustainable agriculture. Adopting integrated soil fertility management practices and reducing agrochemical dependency can mitigate these impacts while ensuring crop sustainability.

Key words: Agrochemicals, crop sustainability, microbial diversity, organic farming, soil quality

INTRODUCTION

The widespread use of fertilizers, pesticides, and insecticides in modern agriculture has significantly boosted crop yields, contributing to the growing global demand for food.[1] However, the long-term impacts of these agrochemicals on soil quality and crop sustainability remain a growing concern.[2] While these inputs are essential for controlling pests and boosting plant growth, their excessive or improper use has been linked to soil degradation, reduced biodiversity, and the disruption of natural soil processes.[3,4]

Fertilizers, though vital for supplying essential nutrients such as nitrogen, phosphorus, and potassium, can lead to nutrient imbalances, soil acidification, and leaching of harmful chemicals into surrounding ecosystems.[5,6] Pesticides and

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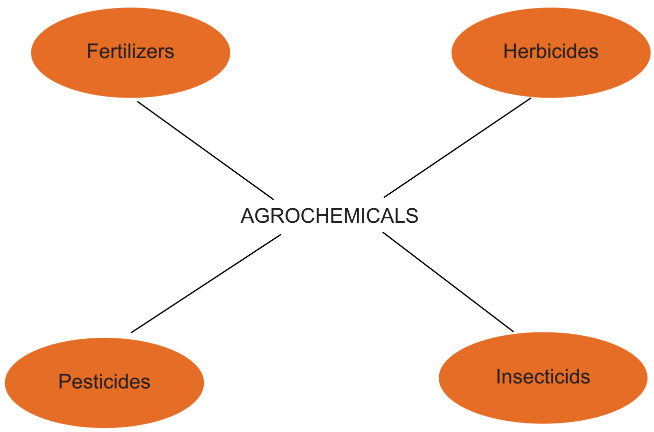
insecticides, while effective at controlling pests, can reduce soil microbial diversity, harm non-target organisms, and disrupt soil food webs, diminishing the soil's ability to self-regulate.[7] Over time, such disruptions can reduce soil fertility, limit water retention, and increase susceptibility to erosion.[8,9]



Given the increasing global reliance on agrochemicals to meet food production demands, it is critical to understand how their cumulative use impacts soil health and agricultural sustainability.[10] This research seeks to address the question of whether continued dependence on fertilizers, pesticides, and insecticides is viable in the long term or if alternative, more sustainable practices are needed to ensure soil vitality and crop resilience. By evaluating various agrochemical treatments, this study will provide insight into how different farming practices affect the soil ecosystem and long-term crop performance, offering valuable guidance for future agricultural policy and practice.

MATERIALS AND METHODS

This study was conducted to assess the long-term effects of fertilizers, pesticides, and insecticides on soil quality and crop sustainability. The methodology involves detailed field experiments, laboratory analyses, and statistical evaluation. Below are the materials and methods, including specific quantities and protocols employed.

Study Area and Experimental Design

- Location: The study was conducted in three distinct agricultural zones (Zone A, Zone B, and Zone C), representing high-input, low-input, and organic farming systems
- Area: Each zone covered 5 ha with plots of 0.5 ha assigned to experimental setups
- Crops studied: Wheat and maize were chosen due to their global significance and diverse growth requirements.

Experimental Treatments

High-input treatment (HIT)
- Fertilizer: 200 kg/ha/year (NPK 20:20:20)
- Pesticides: 1.5 L/ha/year (chlorpyrifos)
- Insecticides: 2 L/ha/year (lambda-cyhalothrin).

Moderate-input treatment
- Fertilizer: 100 kg/ha/year (NPK 20:20:20)
- Pesticides: 0.75 L/ha/year (chlorpyrifos)
- Insecticides: 1 L/ha/year (lambda-cyhalothrin).

Organic farming treatment
- Fertilizer: 5 tons/ha/year (composted manure)
- Pesticides/insecticides: Neem oil at 3 L/ha/year.

Soil Sampling

- Collection: Soil samples were collected at depths of 0–15 cm and 15–30 cm at three intervals: Pre-sowing, mid-season, and post-harvest
- Replicates: Each plot was sampled at five random locations, totaling 15 composite samples per zone per season
- Quantity: Approximately 500 g of soil was collected per sample.

Soil Analysis

Physical parameters
- Soil texture: Determined using the hydrometer method
- Bulk density: Measured by weighing 100 cm^3 soil cores.

Chemical parameters
- pH: Measured using a pH meter in a 1:2.5 soil-water suspension

- Organic matter content: Analyzed using the Walkley-Black method.

Nutrient analysis

- Nitrogen (N): Determined using the Kjeldahl method
- Phosphorus (P): Measured by the Olsen method
- Potassium (K): Extracted using ammonium acetate and measured through flame photometry.

Biological parameters

- Microbial biomass carbon (MBC): Assessed using the fumigation-extraction method
- Microbial diversity: Studied using 16S rRNA sequencing for bacteria and internal transcribed spacer sequencing for fungi.

Crop Yield Measurement

- Parameters recorded: Grain yield (kg/ha), biomass yield (kg/ha), and harvest index (ratio of grain yield to total biomass)
- Harvesting: Plots were manually harvested, and crop weights were recorded using calibrated digital scales.

RESULTS

This section presents the outcomes of the study, evaluating the effects of different levels of agrochemical inputs on soil quality and crop sustainability. Data are analyzed in terms of physical, chemical, and biological soil properties, as well as crop yield performance

Soil Physical Properties

The physical properties of soil, including texture and bulk density, were evaluated across the three treatment groups (high-input, moderate-input, and organic farming).

Description

Organic farming plots had the lowest bulk density, indicating improved soil porosity and structure.

Table 1: Soil physical properties across treatments

Treatment	Texture	Bulk density (g/cm≥)
High-input	Loam	1.55
Moderate-input	Sandy loam	1.45
Organic farming	Loam	1.30

High-input plots exhibited higher bulk density, associated with compaction [Table 1].

Soil Chemical Properties

Chemical properties, including pH, organic matter, and nutrient levels, were significantly influenced by treatment.

Description

Organic farming resulted in neutral pH and higher organic matter content, enhancing soil nutrient retention. High-input treatments showed lower pH and organic matter, indicating soil acidification and degradation [Table 2].

Soil Biological Properties

The diversity and abundance of microbial populations were assessed through MBC and DNA sequencing.

Description

Organic farming demonstrated the highest microbial biomass and diversity, while high-input plots had significantly reduced values, indicating harmful effects of agrochemical use [Table 3].

Crop Yield Performance

Crop yields were evaluated to assess the sustainability of each treatment.

Description

While high-input treatments produced higher initial yields, the decline in soil quality poses risks for long-term sustainability. Organic farming exhibited stable yields and higher harvest indices [Table 4].

Long-Term Impacts on Soil and Crop Sustainability

Description

The results highlight the adverse effects of excessive agrochemical use on soil quality and crop sustainability. Organic farming practices demonstrated better resilience and environmental compatibility [Table 5].

DISCUSSION

The results of this study reveal the profound long-term impact of fertilizers, pesticides, and insecticides on soil quality and crop sustainability, emphasizing the risks of continued agrochemical dependency. High-input farming, characterized by excessive use of chemical fertilizers and pesticides, has been shown to degrade soil health through soil acidification, compaction, and loss of organic matter. These changes reduce microbial diversity and biomass, which are essential for maintaining soil fertility and supporting healthy ecosystems. Over time, this degradation compromises crop yield stability, as evidenced by the decline in productivity in high-input plots.

Organic farming, on the other hand, demonstrated superior soil health outcomes. The higher organic matter content, improved microbial biomass, and balanced pH levels observed in organic plots were linked to more resilient soil systems. The positive correlation between organic matter and crop yields underscores the importance of maintaining soil fertility through natural processes. Organic farming systems not only protect soil physical and chemical properties but also enhance biological activity, which is crucial for nutrient cycling and pest regulation.

These findings suggest that, while agrochemical inputs may offer short-term increases in yield, they come at a long-term ecological cost. The reduction in soil biodiversity and the depletion of soil nutrients can ultimately undermine crop sustainability, as seen in the HITs. The results advocate for a transition toward more sustainable agricultural practices that prioritize soil health. This could involve the use of integrated pest management, reduced fertilizer use, and the promotion of organic matter through composting and cover cropping, which would help mitigate the

Table 2: Soil chemical properties

Treatment	pH	Organic matter (%)	Nitrogen (ppm)	Phosphorus (ppm)	Potassium (ppm)
High-input	5.8	1.2	45	38	300
Moderate-input	6.5	2.0	65	45	350
Organic farming	7.0	3.5	90	50	400

Table 3: Microbial biomass carbon and diversity

Treatment	MBC (mg/kg)	Bacterial diversity (Shannon index)	Fungal diversity (Shannon index)
High-input	150	2.5	2.0
Moderate-input	250	3.0	2.5
Organic farming	400	4.0	3.5

MBC: Microbial biomass carbon

Table 4: Crop yields

Treatment	Wheat yield (kg/ha)	Maize yield (kg/ha)	Harvest index (Wheat)	Harvest index (Maize)
High-input	5,500	6,000	0.45	0.50
Moderate-input	5,000	5,500	0.50	0.55
Organic farming	4,800	5,200	0.55	0.60

Table 5: Summary of long-term impacts

Parameter	High-input	Moderate-input	Organic farming
Soil quality	Degraded	Moderate	High
Crop sustainability	Low (declining yields)	Medium	High (stable yields)
Environmental impact	High	Moderate	Low

negative consequences of agrochemical dependency while ensuring future agricultural productivity.

CONCLUSION

The study highlights the long-term negative effects of excessive fertilizers, pesticides, and insecticides on soil quality and crop sustainability. High-input farming practices led to soil degradation, reduced microbial diversity, and declining crop yields over time. In contrast, organic farming demonstrated improved soil health, higher microbial diversity, and more sustainable yields. The findings underscore the importance of adopting integrated soil management practices and reducing agrochemical dependency to ensure both soil conservation and long-term agricultural productivity. Transitioning to sustainable farming systems is essential for maintaining healthy soils and ensuring the resilience of crop production in the future.

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