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Behavioral Biomonitoring of Agricultural Soil Contaminants using *Caenorhabditis elegans*

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Introduction

Agricultural intensification has significantly improved crop yields but has also introduced a range of harmful contaminants into soil ecosystems, including pesticides, herbicides, fertilizers, heavy metals and plastic residues. These pollutants can disrupt microbial activity, harm soil invertebrate populations and ultimately compromise plant health and food safety. Traditional methods of assessing soil contamination primarily rely on chemical analysis and larger indicator species like earthworms or plants [1]. However, these approaches often fail to detect subtle, early-stage, or sub-lethal toxicity, which may have long-term ecological consequences. This limitation has led to the exploration of alternative methods and *Caenorhabditis elegans* (C. elegans) has emerged as a promising model for behavioral biomonitoring. The nematode's small size, rapid lifecycle, genetic tractability and well-characterized nervous system make it an ideal tool for studying the physiological and behavioral effects of environmental stressors [2]. *C. elegans* exhibits a range of quantifiable behaviors, such as locomotion, feeding, reproduction and chemotaxis, all of which are highly sensitive to environmental changes and chemical exposures. Behavioral alterations in *C. elegans* are often among the earliest detectable indicators of toxicity, providing valuable insights before more severe toxicological effects, like mortality or developmental defects, become evident. With the increasing emphasis on environmentally sustainable farming, C. elegans offers a cost-effective and rapid bioassay platform capable of detecting both acute and chronic toxicity. By integrating this model organism into soil monitoring protocols, agricultural stakeholders can better identify potential toxic threats and take proactive steps to mitigate ecological impacts [3].

Description

The strength of C. elegans in environmental monitoring lies in its ability to exhibit measurable behavioral changes when exposed to environmental contaminants. These behaviors are often dose-dependent and specific to the type of pollutant. Key behavioral endpoints include locomotion, feeding and reproduction. Neurotoxic compounds such as organophosphates or heavy metals impair movement, serving as early indicators of toxicity. Feeding behavior, measured through pharyngeal pumping, is another critical endpoint, with reduced activity suggesting systemic toxicity or stress. Reproductive output, including egg-laying rate and fertility, is also affected by agrochemicals and even low pesticide doses can decrease reproductive success and have transgenerational effects. For soil toxicity testing, researchers prepare contaminated soils either field-collected or artificially spiked and expose synchronized populations of *C. elegans* in controlled lab conditions [4].

Behavioral changes are recorded through microscopy or automated systems and analyzed statistically. The use of genetically modified C. elegansstrains further enhances the sensitivity of these assays. A major advantage of this approach is its ability to detect transgenerational and cumulative effects of pollutants, revealing long-term ecological risks that short-term assays may miss. C. elegans has been used to assess the effects of various agricultural contaminants like insecticides, herbicides and heavy metals. Additionally, it is useful for evaluating the impact of organic amendments and agroecological practices on soil health. While C. elegans offers numerous advantages, challenges exist, such as ensuring effective exposure in solid soil matrices and addressing concerns about its ecological relevance to other soil organisms. Nevertheless, its conserved biological pathways make it a valuable tool for early warning detection of soil contamination [5].

Conclusion

Behavioral biomonitoring using *Caenorhabditis elegans* represents a significant advance in environmental toxicology and soil health assessment. The organism's sensitivity to sub-lethal and chronic exposures makes it an effective tool for early detection of toxic effects through behaviors like locomotion, feeding and reproduction. This ability to detect changes before they cause ecological or agricultural disruptions is crucial for maintaining healthy soil biota, which is essential for crop productivity and nutrient cycling. Incorporating *C. elegans* into soil monitoring allows for more informed decisions about chemical use, land management and sustainability. The model also reveals long-term, transgenerational effects of contaminants, encouraging precautionary agricultural practices. As global environmental pressures increase, the need for cost-effective and sensitive monitoring tools becomes more critical and *C. elegans* meets this demand. While it cannot fully capture the complexity of soil ecosystems, *C. elegans* bridges the gap between molecular toxicology and ecosystem impacts. By combining behavioral assays with other technologies, such as molecular biomarkers and imaging, our understanding of soil contaminants can be further enhanced. This approach supports sustainable agriculture, preserves soil health and ensures long-term food security.

Acknowledgement

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Conflict of Interest

None.

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