

Unveiling the Hidden World Beneath our Feet: The Marvels of Soil Enzymes

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Abstract

Soil enzymes are pivotal catalysts in driving biochemical processes crucial for nutrient cycling and ecosystem health. They facilitate organic matter breakdown, making nutrients available for plant uptake and sustaining soil fertility. The functioning of enzymes is crucial for assessing the health of soil, reflecting responses to environmental factors and human activities. Various enzymes, like dehydrogenase, β -glucosidase, cellulase, urease, phosphatase, and arylsulfatase, play major roles in soil function and can be utilized as bioindicators. Changes in land use, agricultural practices, and pollution significantly influence soil enzyme activities, impacting soil quality and ecosystem dynamics. Understanding soil enzymology is essential for assessing ecosystem function, quality, and responses to natural and anthropogenic impacts, aiding in informed decision-making for sustainable land management. Through further research, the role of soil enzymes in agricultural systems can be better understood, ultimately paving the way for more effective and sustainable land management practices.

Introduction

Soil enzymes are essential markers for evaluating the overall health of soil and ecosystem function, reflecting the intricate interplay between environmental factors and microbial activity within soil ecosystems. As biological catalysts, these enzymes drive essential biochemical processes such as decomposition, nutrient cycling, and pollutant detoxification, ultimately influencing soil fertility and overall ecosystem resilience. Their responsiveness to changes in environmental conditions and ease of use in practical applications render soil enzymes indispensable as bioindicators. They offer valuable information regarding both historical soil management practices and present-day environmental states. By monitoring soil enzymatic activity, resource managers can make informed decisions to enhance soil health, optimize agricultural productivity, and mitigate the impacts of pollution and other anthropogenic disturbances. Thus, understanding soil enzymology is fundamental for

sustainable land management practices, ensuring the preservation of this critical natural resource for future generations.

The Role of Soil Enzymes

Enzymes are biological catalysts, molecules that accelerate chemical reactions without being consumed in the process. In soil, enzymes act as the biochemical machinery responsible for breaking down organic matter into simpler compounds that plants can absorb and utilize. They catalyze a wide range of reactions, including decomposition of plant residues, conversion of organic nitrogen into forms accessible to plants, and the cycling of carbon, phosphorus, and sulfur.

Utilization of Soil Enzymes as Biological Indicators

Dehydrogenase

Dehydrogenase is an essential enzyme found within soil bacteria, serves a crucial function in the oxidation process of soil organic matter, thereby indicating the broader microbial respiratory activity within the soil ecosystem. Its presence serves as a biological indicator of healthy microbial populations and metabolic processes crucial for soil fertility. Testing for dehydrogenase activity involves adding triphenyl tetrazolium chloride to the soil, which, when converted to formazan by bacteria, indicates microbial presence and activity. Monitoring dehydrogenase levels enables understanding of how agricultural and management techniques affect soil well-being, while also indicating the types and levels of pollution present in soils. For instance, higher dehydrogenase activities are associated with lower pesticide doses and pollution from pulp and paper mill effluents, while lower activities are linked to higher pesticide doses and pollution from sources like fly ash.

β -glucosidase

β -glucosidase, a prevalent enzyme in soils, plays an important role in catalysing the hydrolysis of β -glucosides found in decomposing plant debris, thus releasing glucose, a vital energy source for soil microorganisms. It is widely distributed among various organisms, including plants, fungi, bacteria, and yeasts. β -glucosidase activity act as a valuable indicator of soil quality, reflecting past biological

activity and the soil's capacity to stabilize organic matter. Its responsiveness to pH variations and different soil management techniques renders it a valuable biochemical gauge for evaluating environmental shifts, like soil acidification and the presence of heavy metal pollutants. Understanding β -glucosidase activities and their influencing factors is essential for evaluating soil ecosystem status and guiding soil management practices.

Cellulase

Cellulase, a key enzyme in soils, facilitates the hydrolysis of cellulose into glucose, a vital energy source for microorganisms. It consists of three main enzymes: β -D-glucosidase, exo-1,4- β -glucanase and endo-1,4- β -glucanase. Cellulase is produced by various fungi, bacteria, actinomycetes, plants, and invertebrates, contributing to the degradation of cellulose in nature. Inhibition of cellulase activity by fungicides has been observed, suggesting potential impacts on soil microbial activity and cellulose degradation. Comprehending cellulase activity offers valuable information about the physical and chemical characteristics of soil, assisting in the development of agricultural soil management techniques and programs aimed at enhancing soil fertility. Given its crucial role in global cellulose recycling, further understanding of cellulase enzymes is essential for their effective use as predictive tools in soil fertility programs.

Urease

Urease, an extensively prevalent enzyme across various biological contexts, catalyzes the hydrolysis of urea into carbon dioxide and ammonia, with nickel serving as an essential cofactor. Found within both plant organisms and microorganisms, urease manifests in both intracellular and extracellular variants. In soil, extracellular urease, anchored by attachment to organic and mineral colloids, plays a crucial role in urea decomposition. Urease activity stands as a pivotal metric in evaluating soil health, subject to modulation by various factors encompassing organic fertilization, soil tillage methodologies, microbial biodiversity, soil properties, and environmental parameters including temperature and pH levels. A comprehensive insight of urease functionality holds the utmost significance for the proficient administration of urea-based fertilizers, particularly in locales typified by warm weather patterns, substantial precipitation, waterlogged soils, and irrigation infrastructures.

Phosphatase

Phosphatase enzymes are pivotal in facilitating the breakdown of organic phosphorus compounds within soils, liberating phosphate that serves as a nutrient source for plants and microorganisms. Among phosphatases, phosphomonoesterases are extensively researched, targeting various low molecular weight phosphorus compounds containing monoester bonds. Conversely, phosphodiesterases, which degrade phospholipids and nucleic acids to release phosphate from phosphate diesters, have received comparatively less attention despite their significance. The secretion of acid phosphatase by plant roots varies across crop species and varieties, influenced by agricultural practices. Management strategies that impact soil organic carbon levels may also affect phosphatase activity, thereby influencing nutrient availability and plant development. Understanding the dynamics of phosphatase activities within the soil ecosystems is essential for anticipating nutrient dynamics and regulating nutrient uptake to support plant growth.

Arylsulfatase

Arylsulfatase, an enzymatic entity ubiquitously distributed within soil matrices, facilitates the breakdown of organic sulfate esters into phenolic compounds and sulphate or sulphur moieties. Its taxonomy delineates various subtypes contingent upon the specific ester substrate it targets, encompassing alkyl sulfatases, steroid sulfatases, glucosulfatases, chondrosulfatases, and myrosulfatases. Its presence is discernible across a spectrum of organisms, spanning bacteria, fungi, plants, and animals, with bacterial organisms primarily extruding it into the external milieu in response to sulphur deprivation. Notably, its prevalence within soil ecosystems exhibits a pronounced correlation with microbial biomass levels and the tempo of sulphur immobilization processes. The manifestation of arylsulfatase activity in soil is subject to multifaceted environmental influences, such as the impact of heavy metal contamination, variations in soil pH, organic matter abundance and composition, the concentration gradient of organic sulphate esters, and mechanisms conferring protection against enzymatic degradation. Appreciating the intricacies of arylsulfatase dynamics is imperative for comprehensively assessing the intricacies of sulphur cycling within terrestrial ecosystems, particularly its nuanced response to

perturbations induced by environmental perturbations.

Utilizing Soil Enzyme Activity as a Bioindicator for Assessing Soil Ecosystem Health

Soil enzymes serve as Bioindicators of ecosystem disturbance

Land utilization and management methodologies exert notable influence on both the quantity and constitution of soil organic matter, consequently impacting enzyme activities. The processes of de-vegetation and subsequent revegetation play a pivotal role in shaping soil quality, as evidenced by diminished dehydrogenase and protease activities in areas subject to de-vegetation when contrasted with undisturbed soil conditioned. Moreover, the absence of vegetation exerts enduring adverse effects on soil biochemical and microbial dynamics, with soil quality exhibiting sustained impairment even following a 15-year period subsequent to deforestation. Forest fires cause dramatic changes in forest ecosystems, affecting nitrogen loss and altering enzyme activities in soil. While some enzyme activities decrease, others increase after forest fires, with urease activity showing a time-dependent recovery after burning. Additionally, climatic conditions, such as drought, influence soil quality by affecting enzyme activities, particularly those involved in nitrogen cycling.

Utilization of Soil Enzymes as Bioindicators for Assessing Alterations in Agricultural Techniques

Various fertilization practices influence soil enzyme activities differently, with organic fertilizers such as farmyard manure enhancing microbial biomass and enzyme activities compared to mineral fertilizers, particularly under rotations. Different types of mineral fertilizers also affect soil enzyme activities differently, with nitrogen fertilizers inhibiting enzyme activities while phosphorus and potassium fertilizers promote them. Organic fertilizers, such as compost and vermicompost, significantly increase soil enzyme activities and microbial properties, leading to improved soil quality. The application of organic amendments influences soil enzyme activities depending on their nutrient content, with higher rates of organic amendments favouring soil quality parameters. Moreover, organic amendments can suppress plant diseases by enhancing antagonist microorganisms and microbial biomass, with arylsulfatase identified as a useful indicator of disease suppression.

Tillage practices significantly influence soil enzyme activities and soil quality parameters, with no-till systems generally providing better enzyme activities compared to conventional tillage systems. For instance, dehydrogenase activity increases under continuous zero-tillage practices, while cellulase activity is greater in conventional tillage systems. Additionally, different tillage depths affect soil enzyme activities differently, with shallower ploughing resulting in greater enzyme activities in the upper soil layer.

Irrigation practices also impact soil enzymatic activities, with more frequent irrigation increasing phosphatase and catalase activities but decreasing urease activity. Overall, various agricultural practices like fertilization, tillage, and irrigation influence soil enzyme activities and microbial properties, thereby affecting soil quality and ultimately crop productivity.

Soil Enzymes - Bioindicators of Xenobiotic Pollution

Xenobiotics, including pesticides and heavy metals, pose significant challenges in soil environments, impacting various biological and biochemical processes. Pesticides can disturb local metabolism and enzymatic activities in soils, with both negative and positive effects reported. Various pesticides can either enhance or hinder soil enzyme activities, contingent upon factors like their chemical composition, concentration, soil type, microbial community composition, and prevailing environmental conditions. The influence of pesticides on soil enzyme activities can exhibit dualistic characteristics, manifesting as both detrimental and advantageous effects. This dichotomy in their impact is contingent upon the particular pesticide and enzyme involved, alongside the enzyme's functional state. Repeated applications of pesticides over many years can have lasting effects on soil enzyme activities, reducing biological activity and enzyme catalytic behaviour. Additionally, environmental pollution from heavy metals and trace elements can inhibit enzyme reactions through various mechanisms, including complexation with substrates or protein-active groups. Some ions may act as cofactors or activators, while others can react with enzyme sulfhydryl groups, leading to inactivation or inhibition.

Heavy metal contamination, such as zinc, can cause significant inhibition of various soil enzymes, with different enzymes exhibiting varying sensitivities to contamination levels. Soil acidification can exacerbate the negative effects of heavy metal

contamination on enzyme activities. Furthermore, the oxidation state of metals influences their toxicity, with certain states being less harmful due to precipitation or complexation reactions in soils.

Conclusion

Soil enzymes are regarded as valuable indicators of soil quality owing to their close association with soil biology. They offer practical, sensitive, and holistic insights into soil health and are

often likened to "biological fingerprints" reflecting past soil management practices. Soil enzymes also provide indications of soil fertility, quality, and changes resulting from pollution. However, their activities can be affected by various natural and human-induced factors, to varying extents. Exploring microbial diversity in soil to discover new enzymes represents a promising approach to enhance soil enzyme activities and improve overall soil ecosystem health.

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