



Future of Soil Science under Present Scenario

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Abstract: Soil is a critical natural resource central to food security, climate regulation, carbon sequestration, and ecosystem sustainability, yet soil science remains underprioritized in modern research and policy. With soils storing more carbon than atmospheric and vegetative pools combined, improving carbon flux quantification and sequestration strategies is increasingly urgent. The future of soil science depends on integrating artificial intelligence, machine learning, nanotechnology, remote sensing, and data analytics to enhance soil characterization, digital mapping, precision nutrient management, and real-time monitoring.

Key words: Integrating knowledge, digital mapping real time monitoring.

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Soil has a great role in everyday life. It filters the water we drink. It grows the food we eat. It has the capacity to capture the carbon dioxide that causes the climate change. In fact, it holds more carbon than all terrestrial plant life on the planet. It has 1500 billion tons of carbon which is much higher than carbon stored in the atmosphere (760 billion tons) and in vegetation (560 billion tons). Beside climate change it has greater role in food security and environmental sustainability as well as ecosystem restoration. But in present days, soil science is very much neglected subject and role of soil in sustaining food productivity is ignored in many instances. Therefore, we need to change our traditional outlook and integrate our research on complex interconnected disciplines and subjects like computer science, engineering, urban planning, nanotechnology, data sciences as well as several industrial and environmental sectors.

AI (Artificial intelligence) can help in accurate soil analysis with greater monitoring and management practices. AI powered tools can easily be used for soil mapping, remote sensing and precision agriculture. It may play a great role in soil science job market, emphasizing the need of adoptability and continuous learning. AI tools are very smart to remove the noise from soil water content, electrical conductivity and dielectric constant data from soil parameters. It can play the role also to understand soil organic carbon stocks or soil fertility prediction. Actually machine learning models may very fast analyze massive data sets collected from drones, LiDAR and GPS. AI can very well identify the patterns, easily detect the anomalies and generate 3D models and maps automatically. It can also very well identify the soil defects.

It is now urgent to quantify and analyze the flow of carbon within a soil ecosystem, including inputs, outputs and storage. Days have come to develop strategies to understand the global carbon cycle to enhance carbon sequestration, mitigate climate change and improve soil health. It will offer a fairly good idea about physical degradation, microbial activity, water storage and plant availability of nutrients beside to protect the soil from erosion. It is very essential to know the vast and diverse microbial communities and their function in soil. The complex interactions between soil, plants and environment are very important to know for developing truly digital mapping and classification system. Soil health assessment, integration of data science and interdisciplinary approaches is presently needed. The modern outlook of soil health assessment should emphasize an integrated dynamic view of soil and clearly indicate its multiple ecosystem services. It is not the approach of simply measuring the nutrient levels but also to consider physical, chemical, biological properties beside living biota (both micro and macro) and their interactions for sustainable soil health assessment.

Nanotechnology can help innovative solutions for enhancing soil health, improving crop productivity and promoting sustainable agriculture. Nanomaterials may effortlessly solve the problem of nutrient management, soil remediation and disease control. Nano sensor can easily monitor the soil after offering powerful toolkit for soil health management, detects soil contaminants and help to improve agricultural practices. It assists to precisely monitor and manage soil conditions, leading to more crop yield and sustainable production. Nanofertilizer may help to overcome long lasting problem of nutrient use efficiency and soil native nutrient mobilization.

Application of nanofertilizer may release nutrients slowly resulting in extended nutrient release. For example, normally release of nutrients from the chemical fertilizer are generally lasting for 4-10 days while nutrient release from nanofertilizer lasted from 35-40 days and thus would requires less frequent application of nutrients. Moreover, foliage application of nanofertilizer may trigger the different plant co-enzyme system which may results in enhanced release of beneficial enzyme

Table 1. Nano-induced beneficial enzyme activities in the rhizosphere (average of 10 crops)

Name of beneficial enzyme	Increase in activity (%)
Dehydrogenase	25-68
Esterase	23-90
Acid phosphatase	21-72
Alkaline phosphatase	18-136
Phytase	23-83
Nitrate reductase	12-87
Aryl sulphatase	19-68
Cellulase	104-212
Hemicellulase	52-87
Lignase	23-65
Amylase	20-126
Chitinase	27-72
Lipase	32-67
Protease	39-108

from the plant roots. These enzymes could help to mobilize unavailable plant nutrients from the soil by the plants. Nanofertilizers have the potential to interact with soil in different ways and influence its physical, chemical and microbial communities which may results in more soil carbon sequestration potential, nutrient uptake and soil health improved. The improvement of beneficial enzyme activity in the soil under plant rhizosphere due to foliage application of nanofertilizer is presented as Table 1.

There is a need to holistic focus on soil borne pathogens combining microbiome studies, climate change impact assessment, nanotechnology and molecular diagnostics to overcome these problems. Understanding the specific pathogens and their life cycles is essential for tailoring the most appropriate management strategies. Long term soil conservation technology is needed after emphasizing to prevent erosion and adopt the appropriate technologies like no-till farming, terracing, contour farming, crop rotation, wind breaks, cover cropping and use of organic matter as and when needed.

Data science plays a pivotal role in soil science to get more efficient and sustainable agricultural practices. After analyzing the data from sensors, satellites and historical records it immensely help in understanding soil properties, optimizing resource management, predicting yield of the crop and help to overcome risk

associated with farming. It also assist farmers in decision making, productivity increase from the same land after minimizing environmental impact. After analyzing the vast data it can very well predict soil behavior. Sensors and remote sensing technologies provide real time data on soil conditions and facilitate precision farming, weather pattern and may also help to minimize environmental impact. It also assist in identifying optimum planting time and manages risk associated with diseases and pest. Data driven insights can also help in managing soil erosion, supply chain and ultimately food security.

Soil science can play critical role in industrial and environmental sectors after providing

the tools and knowledge for sustainable soil resource management. It may also help in land reclamation, pollution remediation and assist to understand the climate change impacts. In the industrial sectors it can play enormous role for resource extraction and management, construction beside help in minimizing environmental impacts. In fact soil science future depends on innovative technologies and sustainable practices. The field is open out from primarily fundamental sciences to one fascinated on practical, real-world solutions, with an increasing emphasis on interdisciplinary collaboration and translating research into policy.

