__Review Article__

TECHNOLOGY INNOVATION: A GREEN APPROACH TO SOIL HEALTH

Abstract

Soil is a vital source of nutrients and a medium for plant growth and microorganisms. Land degradation due to excessive and imbalanced agrochemicals, and improper agriculture practices, has resulted in soil to loss its productivity and fertility to crops. Climate change being one of the factors wherein incorporating organic practices with new innovative technology can alleviate the need of unsustainable agricultural practices. This paper, highlights the importance of organic fertilizers and their utility, the potential of new innovative technology along with precision agriculture and A. I Integrating modern technology with organic farming practices can aid soil health and mitigate diverse effects on soil. This can help address the challenges of a changing climate and environment.

Keywords: Soil health, Organic practices, Technology innovation, Precision Agriculture, AI

Introduction

Healthy soil is a critical factor in determining plant growth and development. Soil health is not only confined to the wellbeing of plants but the overall growth of microorganisms and the functionality of soil as a living ecosystem. The decrease in nutrient use efficiency as well as agricultural productivity is a direct results of deteriorating soil health. Nutrient mining is another term used to indicate the negative balance between nutrient addition and nutrient removed by crops. At present, Indian soils are at negative balance of 8 to 10 million tons per year (NAAS, 2018), therefor maintaining soil in optimum health is a pre-requisite to support necessary food grain production and sustain ecological services (Katyal *et al.*, 2016).

According to the National Bureau of Soil Survey and Land Use Planning, around 30% of the soil in India is degraded. This gains further importance, since recent estimates show a loss of 24 billion tons of fertile soil every year, an alarming trend that could have more than 90% of Earth's land area degraded by 2050 (Gomiero, 2016). Excessive ploughing, planting the same crop year after year and excessive fertilizer use impacts approximately 33% of the planet's land area (FAO and ITPS 2015). Some of the unintended consequences include soil acidification (Marris, 2022), nutrient imbalance (Zhang *et al*., 2015), negative impacts on soil biota (Strecker *et al*., 2021), and soil pollutions (Zhang *et al*., 2015, Gu *et al*., 2023). Many anthropogenic activities have added threats to the health of soil ecosystems, leading to the loss of biodiversity (Estrada-Carmona *et al*., 2022), decline in organic matter (Lal, 2020), and irreversible salinization (Hassani *et al*., 2021). About 70% of soils suffer either from soil acidity (22.9%) or alkalinity (41%), Water logging causes salinization (Saline 32%) and damages soil, resulting in an annual loss of 1.2 to 6.0 m tonnes of grains. (Reddy, 2023. National Soil Health Card (SHC))

Over six decades of green revolution, the use of fertilizer nutrients has increased from 0.30 Mt in 1960-61 to 32.54 Mt in 2020-21. (Das *et al*, 2022). The effect of fertilizers pesticides, fossil fuel energy, accumulation of toxic compounds (Agrochermicals) coupled with intensive tillage and mono-cropping has had a negative impact on soil health. National Soil Health Card (SHC) mission revealed the deteriorating health of Indian soil, ie., primary nutrients was found deficient at 96% for N, 61% for P, and 62% for K and about 52.1% in organic carbon. Deficiencies of more than one micronutrient along with primary soil nutrients have also been reported at several locations in the country. There are deficiencies of micronutrients like Sulphur (24.7%), Iron (25.8%), Zinc (35.5%) Boron (18.1%), Manganese (14.6%). Thus, both primary and micronutrient deficiencies have now become the major constraint in sustaining high crop yields in present-day intensive agriculture across India. (Das *et al*, 2022). Climate change has further exacerbated soil health. Due to rapid progressing water deficits and climate change, results of improper soils use has worsened (Baghbanzadeh *et al*., 2017) .According to a report, India lost approximately 5.04 million hectares of crop area due to cyclones, floods, cloudbursts, and landslides (Mahapatra, 2022).

To address these challenges, proper farming strategy with smart innovations, Sustainable soil practices, can help alleviate the use of excessive mineral fertilisers/ agrochemicals. Building soil fertility through the use of natural soil additives and organic manures, using water resources efficiently, and properly managing waste, are designed to combat soil degradation, support formation, and soil health. (Buzzard *et al*., 2021; Sharma *et al*., 2022).

Startups and scaleups are also developing technological solutions with a sustainable approach with an aim to mitigate soil stress and improve agricultural productivity. Technology innovation have greatly shaped agriculture throughout time. From creation of plough to Global positioning system (GPS) resulting in more efficient use of resources and soil management. Agricultural technology along with organic farming with emphasis on soil health needs to be explored to enhance utilization of resources without exploiting the environment more than it has already been (Anonymous, 2024).

UNLOCKING AGRICULTURAL SUSTAINABILITY THROUGH ORGANIC PRACTICES AND SMART INNOVATION TECHNOLOGY

Diversifying Nutrient Sources

Monotonous excessive use of chemical fertilizer can result in soil and water pollution, negatively impacting not only crops but the ecosystem and human health as well. The imbalance use of these fertilizers and lack of attention for fertilization of secondary nutrients, such as sulfur, and micronutrients, viz. Fe and Zn, lead to their widespread deficiency (Tandon, 2013). Use of only one nutrient source cannot fulfil the demand of crop as well as the soil, therefor nutrients of different sources should be incorporated. Different nutrient sources through agro industrial wastes, minerals (without processing), green and brown manures, weed manures, and bio-fertilizers (Shahane and Shivay, 2021). INM can also improve soil health by integrating organic sources and reducing the use of only chemical inputs. Use of biofertilizers containing beneficial microorganisms can additionally improve soil fertility and soil productivity. These additives not only improve soil structure, health, and resilience by enhancing plant tolerance to salt and drought stress but also provides soil with nutrients such as nitrogen, phosphorus, potassium, essential micronutrients and organic matter. These technologies have been derived naturally or synthetically. At present, the selection of nutrient source should be such that it provides multiple nutrients for higher yield, has considerable residual effects, and positive influence on soil properties, thereby on soil health and less on environmental footprints. *(*Shahane and Shivay, 2021)

Organic Manure Production Technique

Liquid fermented organic manure (LFOM): LFOM is the liquid extract obtained during the fermentation or decomposition process. LFOM can be applied directly to the soil or used as a foliar spray.

Practical utility of Innovation

1. Beejamrit (mixture of local cow dung, urine, water and lime stirred)
2. Panchagavya (Mixture of 5 kg cow dung, 4 litre urine, 3 litre milk, 2 litre curd, 2 Kg of pulses flour, 1 kg ghee, 2 Kg jaggery and 10 litre water and kept for 15 days)
3. Enriched panchagavya (Cow dung, cow urine, cow milk, curd, jaggery, ghee, banan, tendercoconut water)
4. Amrithakaraisal (Amrit Solution) (Cow dung, cow urine, jaggery)

Fermented organic manure (FOM): These manures are rich in essential nutrients like nitrogen, phosphorus, and potassium. FOM is the solid residue that is obtained after fermentation and decomposition of organic materials

Organic manure is a mixture of plant residues or animal origin viz; FYM, pig manure, poultry manure, goat/ sheep manure, press mud, green manure (sesbania), azolla, city compost; an organic material found in urban solid waste.

1. Ghanajeevamritha (solid form of *Jeevmaritha*): Cow dung and urine are mixed with pulse flour, jaggery made into ball like structures and dried under the shade

Others

Vermi wash: 1 kg adult earthworm devoid of cast resealed in 500 ml Luke warm water (37 to 40 degree C) and agitated for 2 minutes, the released mucus and body fluids collected and mixed for spray.

Compost tea: Fresh compost suspended in barrel for 7 to 14 days

Unseeded weeds and weed clippings + water in 1:10 in a barrel for 3 days.

Egg shell Crushed + water, a rich source of calcium, help prevents blossom end rot in tomatoes.

Crop residues- Rice straw, wheat straw, sorghum stalk, pearl miller stalks

Oil cakes-Castor, cotton seeds, neem, sunflower, neem, linseed

Biofertilizers are ready to use live formulates of beneficial microorganisms that on application to seed, root or soil mobilize nutrients through their biological activity in particular, and help in building up the micro-flora and soil health in general. It includes, blue green algae (BGA), rhizobium, azotobacter, azospirillum, phosphate solubilising and mobilising bio inoculants (PSB) and plant growth promoting rhizobacteria (PGPR). (Kumar *et al.*, 2022)

Mountain Microorganisms

A collection of various beneficial microorganisms found in virgin soils or forest decomposing organic matter. It can be used in the preparation of solid and liquid organic fertilizers. They can also be applied directly on the plant leaves to control certain pests and diseases or as a growth booster

Practical utility of Innovation

1. decomposing forest leaves (debris) + 10 kg of rice/wheat or maize bran+ 1 litres of molasses + 3 litres of clean water (not contaminated)

2. Bokashi- 1 sack of chicken manure, 1/2 sack of charcoal or carbon dust, 1 sack of saw dust, 2 litres of molasses, 2 litres of activated mountain micro-organism solution, 1 sack of rice or coffee husks, 1/2 sack of chopped green grasses and banana stems, 2 kg of wood ash, 2 kg of fresh cow dung. After mixing and the moisture content is right leave the material in a heap-like structure. On the 15 day after preparation, when it cools, the bokashi fertilizer is stored in gunny sacks and applied during rainy season.
3. Fermented kitchen waste, garden waste, agricultural residues, virgin mountain soils or forest decomposing organic matter
4. Fermented plant juice-Plant juice extracts (weeds, green leafy vegetables), sugar, microbial innoculants.

Technology innovation

Drought Combating

Hydrogels also known as superabsorbent polymers (SAP), reduces the use of fertilisers, while improving soil properties. SAP are not toxic to plants or the environment, (Marczak *et al*., 2022). Hydrogels have also been used in agriculture as soil amendments to improve soil hydraulic properties (Al-Darby, 1996). Agriculture, being one of the highest consumers of water, benefits substantially when soil amendments are added to soil to prevent water stress, or for improving soil physical properties. Hydrogels alter soil structure decreasing the number of drainage pores and retaining water. Like soil water infiltration, hydrogel application mostly decreased soil evaporation as soil water is bound to the hydrogel, reducing how much water is lost to the atmosphere. Hydrogels near the soil surface can also increase evaporation by storing water making it easy for stage one of evaporation to occur. (Adjuik *et al*., 2022). Numerous studies have described the benefits of using SAPs in agriculture and horticulture, where they have contributed to the reduction in water stress, increased yields, and the improvement of biometric parameters (Varela *et al*., 2016; Yang *et al*., 2019) and the positive influence of natural soil additives on the availability of soil nutrients nutrients (Bhattacharyya *et al*., 2007; González-Coloma *et al*., 2022; Kulczycki and Sacała, 2020). WAGs (water-absorbing geocomposite) are a new type of soil additive with a spatial structure that fully benefits from the sorption capacity of superabsorbent polymers and eliminates some notable limitations. A new biodegradable version of a water-absorbing geocomposite (BioWAG) manufactured from natural animal/plant fibres is one of the few solutions which improves water retention and provides a source of nutrients for plants. The application of waste materials enables an increase in carbon sequestration in the soil and closed-loop fertilisation is an efficient form of recycling. (Marczak *et al*., 2022).

Fonio

A deep rooted crop grain grown in Africa cultivated in area with scarce water with high counteract desertification, soil erosion and tolerate harsh environmental conditions. Fonio is a nutritious and gluten-free grain that can be grows on sandy soil without fertilizers or pesticides, providing a high-value and drought-resistant crop.

Bioinoculants

Bio fungicides and innoculants enhance soil fertility, increase crop yields, reduce fertilizer use, and restore degraded soil affected by salinization or erosion. Ancient microbes known as extremophiles that promote growth under the most extreme conditions when added to soil can be used as seed treatment to significantly increase root mass, length, and density, improving soil health and resistance at the same time. High-quality worm castings free of pesticides, chemical additives, and genetically-modified organisms (GMOs) can be used as an effective alternative to commercial fertilizers

Soil Remediation & Restoration Practices

Toxic compounds that tend to accumulate due to industrial processes, improper waste disposal excessive use of agrochemicals as fertilizers, plant protection and weed management affect soil health. Some organic sources of crop nutrition, such as sewage and sludge and night soil, are also reported to contain a high amount of heavy metals (Walia and Goyal, 2010; Saha *et al*., 2018), causing adverse effects on soil health. Utilizing nanoparticles or nanomaterials to target and neutralize contaminants effectively are emerging.   Additionally, electrokinetic remediation, harnessing electric currents to decontaminate soil sources, also a promising technology for soil remediation. Rapid removal of contaminants or under immediate threat to soil and human engineered microbes which require less time to degrade the pollutants may be a preferred option. A specially engineered microbes employed to break down contaminants in the soil are becoming an effective way to degrade pollutants and boost soil fertility restoring soil structure and microbial diversity. Startup such as Fixed Earth Innovations: Microbial Marvels for Soil Health, Canadian startup employs specially engineered microbes, the startup offers a tailored solution. The deployment of these microbes is customized on a site-specific basis, providing a targeted approach to restoring soil microbial health. Fixed Earth Innovations addresses a spectrum of contaminants, including hydrocarbons, salinity, sulfolane, and per- and polyfluoroalkyl substances (PFAS), reducing environmental liabilities and promoting sustainable agriculture practices.

Phytoremediation and Bioremediation

Phytoremediation uses higher plants to rehabilitate soil and groundwater contaminated with metals, pesticides etc. It is environment friendly and cost effective, however it works best when the contamination level is low. It is achieved by phytoextraction (phytoaccumulation), phytovolatilization, Phyto stabilization, or phytodegradation (Yan *et al*., 2020). Indian mustard (can be used as green manure and weed control), Indian grass- (Gramineae family) remediate petroleum hydrocarbons, Tagetes erecta (Heavy metals like lead, cadmium, copper and chromium), Water hyacinth, Sunflower, Willow tree, etc.

While bioremediation involves use of microbes (namely bacteria, fungi and micro algae) naturally available in the environment to clean the contaminated areas. Certain microorganisms especially bacteria, microalgae and cyanobacteria have the ability to utilize hazardous organic contaminants as sources of their carbon, energy or other nutrients (Megharaj *et al*., 2014) thereby stimulating their growth. Adding ammendation such as molasses and vegetable oil may improve their growth.

Soil Compaction Control

Soil compaction is a form of soil degradation as a result of reduced pore space for air and water due to excessive heavy machinery use. The conventional plough tillage involves physical manipulation of soil; therefore, it has several implications on soil health that can be seen primarily on soil physical health, soil biological health, and lastly on soil chemical health. (Shahane and Shivay, 2021. A biologically healthy soil is less prone to soil compaction. Soil compaction have several negative effects such as decreased fertility, water infiltration, and inability of soil to supply nutrients to plants, increased soil erosion, Co_2 emission, flooding reduced plant as well as root growth and yield. Conservation tillage improves soil physical and chemical properties, additionally added crop residues are a source of plant nutrient thereby making soil healthy. Conservation tillage system is based on three major principles, viz. continuous or minimal mechanical soil disturbance, maintenance of a permanent biomass soil mulch cover on the ground surface, and diversification of crop species (Kassam *et al*., 2019) with a combination of fibrous and tap root crops (include forage, cereals, oilseeds and pulses crop) which also creates a deep-rooted channel and add organic matter to the soil (Anonymous, 2010). Conservation Tillage such as No Till i.e., growing crops without soil disturbance, mulch Tillage i.e., soil disturbance but crop residue maintained on the soil. Reduces the intensity of soil tilling or eliminating it altogether to preserve soil structure and reduce erosion.

Precision agriculture:

Precision agriculture, also known as site-specific farming, combines geospatial data and technology to enable more efficient and targeted soil management. One of the key tools in precision agriculture is the use of geographic information systems (GIS). GIS integrates various data sources such as satellite imagery, soil sample analysis, and weather data. By analysing these maps, farmers can identify variations in soil properties and make informed decisions regarding nutrient application, irrigation, and crop selection. This approach minimizes the risk of overuse or underuse of resources, leading to improved soil health and increased crop yields.

Application of Artificial Intelligence (A.I)

The integration of AI in food production has led to a 20% reduction in emissions from the agricultural sector. The infusion of AI technology in agriculture serves as a valuable tool for controlling and managing unforeseen natural conditions, further fortifying the resilience of the industry. This seamless integration of AI into agriculture marks a significant leap forward, ensuring sustainable and technologically advanced practices in food production (Chaudhari *et al*., 2024).

A detailed soil maps and use of soil sensors and monitoring devices, measure key soil parameters, including moisture content, temperature, nutrient levels, pH levels. nutrients, organic matter, and microbial activity. This helps to manage land and optimize their soil health and productivity, as well as detect and prevent soil degradation, erosion, nutrient depletion, or contamination. LoT sensors and soil monitoring drones, provide accurate, timely, and affordable soil information, also leveraging of machine learning algorithms and robotics helps to access real-time data on soil quality, leading to more efficient use of resources and higher crop yields.

Map creation using GPS and satellite technology can be an interactive platform for path planning and optimization on-farm activities. A combination of geospatial intelligence and path-planning simulations for machinery use and robots can plan field operations efficiently. After the creation of soil maps, the platform enables farmers to modify and optimize resources to best fit their individual requirements. Remote Sensing with Satellite imagery and drones equipped with AI algorithms can assess soil health and detect issues like erosion or nutrient deficiencies.

Autonomous or semi-autonomous vehicles known as controlled traffic farming (CTF) perform precision farming tasks and GPS-guided equipment, minimize soil compaction caused by heavy machinery, wherein farmers limit heavy machinery traffic to specific lanes within a field, reducing soil compaction. This reduces input costs, soil compaction, and erosion allowing to keep in track of the path the equipment is travelling.

A cable-driven robot covers a farm and performs various farming operations from the sky down using winches on top of masts and cables. It works on any soil type and slope as well as operates automatically according to weather and time conditions. The compaction control robot thus reduces the amount of chemical application needed to grow crops and solve issues of soil compaction, improving crop quality and yield. This robot offers a cost-effective, modular, and efficient way to reduce foot and tire traffic on the soil and hence maintain soil health making farming more sustainable.

The integration of robotics and automation in soil health management has opened new avenues for enhancing agricultural practices. Drones and robots equipped with various sensors and imaging technology are being used to collect high resolution data, monitoring crop health and asses soil properties.

Conclusion

The integration of artificial intelligence in organic farming presents a promising avenue for enhancing soil health and promoting sustainable agriculture in India. By leveraging AI technologies, farmers can optimize their practices, resulting in improved soil quality, higher yields, and greater economic viability. Continued investment in technology, training, and infrastructure will be crucial for realizing the full potential of AI. By leveraging the capabilities of AI for monitoring, precision agriculture, and predictive analytics, farmers can enhance productivity while minimizing environmental impact. Embracing this synergy of nature and technology may usher in a new era of agricultural revolution, addressing the challenges of food security in an ever-changing climate. A holistic approach that integrates modern technology with organic principles will be essential in fostering resilient and sustainable farming systems for the future. Harnessing these modern technologies, communities can adapt to contemporary challenges without losing the wisdom of their ancestral practices.

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