Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 04, Issue: 05 (SEP-OCT, 2024)
Available online at http://www.agriarticles.com
©Agri Articles, ISSN: 2582-9882

Technological Innovations in Soil Fertility: Integrating IoT and Precision Agriculture for Optimal Nutrient Management

(*Aniket Sunil Gaikwad)
Ph.D. Research Scholar, Department of Soil Science, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, Ahmednagar, Maharashtra, India – 413722
*Corresponding Author's email: aniketgaikwad1963@gmail.com

The pursuit of sustainable agricultural systems has led to significant advancements in soil fertility management, notably through the adoption of precision agriculture. This approach emphasizes the implementation of best management practices tailored to the unique characteristics of each field. Key to this strategy is the efficient management of nutrients, where the principles of applying the right source, rate, time, and place can be optimally achieved through advanced tools and technologies. These include soil sampling techniques, variable-rate fertilizer application systems, and yield measurement technologies, all of which contribute to the formulation of site-specific nutrient management plans. Central to improving nitrogen (N) efficiency, proximal crop sensors have emerged as valuable tools, enabling real-time adjustments to fertilizer applications based on variable crop needs. These sensors facilitate precise fertilization, enhancing productivity by accurately identifying the required nutrients and their optimal application rates. Site-specific nutrient management (SSNM) represents a dynamic approach to nutrient management, emphasizing localized strategies that address specific soil and crop needs. By optimizing nutrient supply in alignment with crop demand, SSNM aims to enhance yields, improve fertilizer use efficiency, increase profitability, and promote environmental stewardship. The integration of the Internet of Things (IoT) into agriculture marks a pivotal advancement in precision farming. IoT enables seamless monitoring of soil conditions, providing critical data on moisture content, temperature, and pH levels. This technology empowers farmers to make informed decisions regarding irrigation and fertilization, leading to improved resource management and sustainability. Various technologies, such as Geographic Information Systems (GIS) and remote sensing, further enhance precision agriculture by allowing for spatial analysis of soil and crop data. These systems facilitate the identification of nutrient deficiencies and enable farmers to make data-driven decisions that maximize productivity and minimize environmental impact. Emerging sustainable inputs, such as biochar and seaweed extracts, are gaining recognition for their potential to improve soil fertility and enhance nutrient retention while reducing greenhouse gas emissions. These innovative practices underscore the need for ongoing research and adoption of environmentally friendly agricultural practices that contribute to soil health and overall agricultural sustainability.

Keywords: IoT, SSNM, GIS, GPS, Remote sensing, Precision agriculture and Sensors

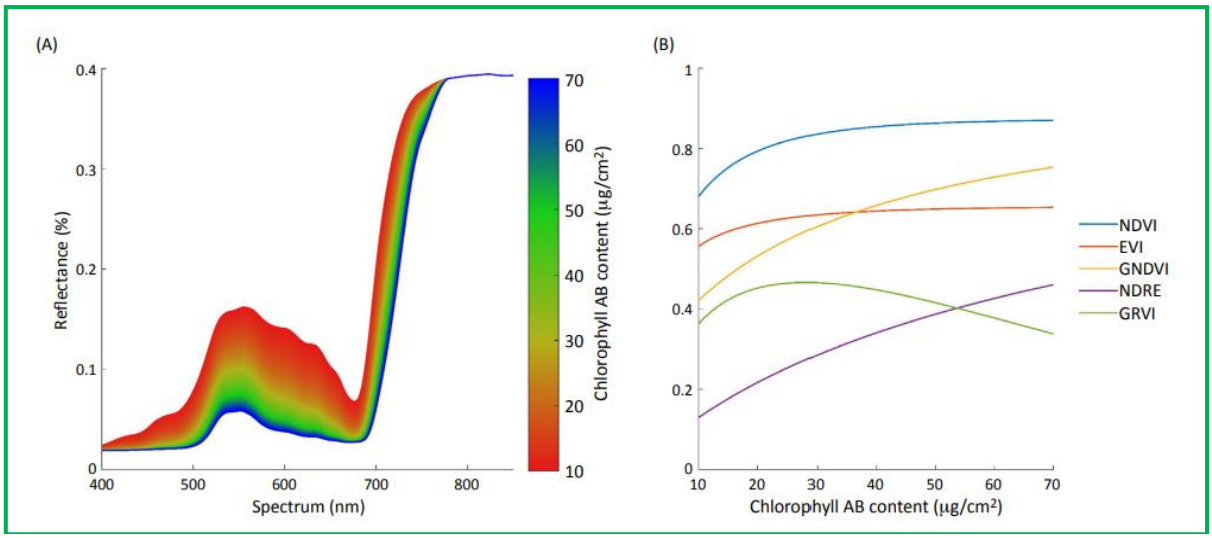
Precision Agriculture

The systematic implementation of best management practices into a site-specific system provides the optimal opportunity to cultivate a genuinely sustainable agricultural system. Effectively managing the right source of nutrients at the right rate, right time, and in the right

place is best achieved with the appropriate technological tools and methodologies. Various advanced technologies, including remote sensing, geographic information systems (GIS), and precision agriculture techniques, are available to facilitate informed decision-making related to nutrient management. These technologies enable accurate soil sampling, precise fertilizer application, and comprehensive yield measurement, ensuring that interventions are tailored to the unique conditions of each field. By integrating these innovative tools, farmers can develop a site-specific nutrient management plan that not only optimizes crop production but also minimizes environmental impact and enhances soil health. This holistic approach ultimately contributes to the long-term sustainability of agricultural practices, ensuring food security and ecological balance.

Assessment of Nutrient Status

- With improved nitrogen (N) efficiency being a key focus of modern agriculture, the use of proximal crop sensors to define variable rate fertilizer application is one of the classic applications of precision agriculture
- Several commercial multispectral systems are available for installation on tractors and boom sprayers, providing real-time variable fertilizer rates.



Smart Fertilization System

- Manual spraying is a common technique used for fertilization. However, the optimal way of fertilization requires sensing capabilities to find the exact place where fertilizer is needed, which chemical components are missing and the amount of fertilizer needed. It is important to provide fertilizers in a very precise amount in order to improve productivity.
- An automated fertilization system has real-time sensors to measure the soil fertility. The system consisted of three modules including input, output and decision support. The decision support module measured the optimal amount of fertilizers needed for the growth of the plants based on the real-time sensory data captured by the sensors.
- A mechanical sensor named the "Pendulum Meter" which was used for optimal fertilization. This sensor was mounted on the tractor to measure the density of the crop, so the corresponding fertilizer spreader was controlled based on the readings of this sensor.

Site specific nutrient management

- "Site-specific nutrient management (SSNM) is the dynamic, field-specific management of nutrients in a particular cropping season to optimize the supply and demand of nutrients according to their differences in cycling through soil-plant systems." (Dobermann and White, 1999).

- Addressing nutrient deficiencies which exist within field and making adjustment in nutrient application to match these locations or soil differences.

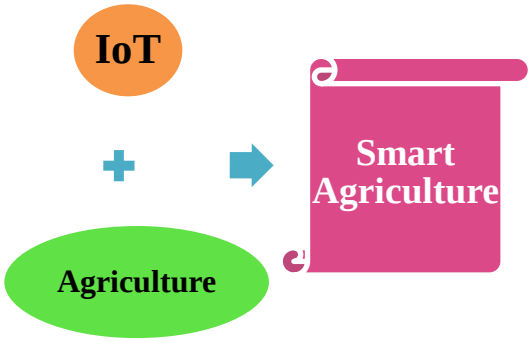
Aims of SSNM

- Provide a locally-adapted nutrient best management
- Practice (BMP) tailored to the field- and season specific needs for a crop
- Increase in yield
- High efficiency of fertilizer use
- Improve profitability
- Improve marketable crop quality
- Improve environmental stewardship

Internet of Things (IoT)

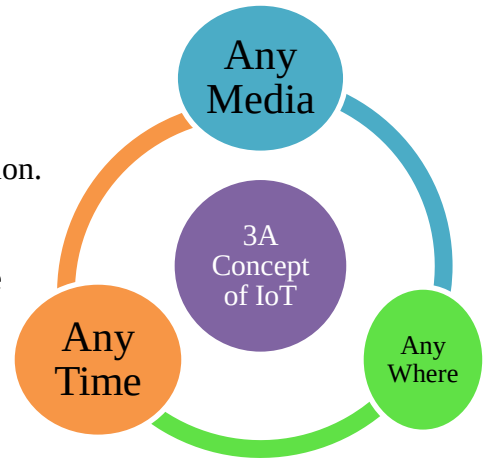
Internet of Things (IoT)

- ***People, process, device and technology + sensors and actuators***
- **Term proposed by Kevin Ashton in 1999**



Features of IoT in Agriculture

- A central component of Precision Farming.
- Second wave of green revolution.
- Daily monitoring of crop online in a seamless fashion.
- Enhance the traceability of agricultural products

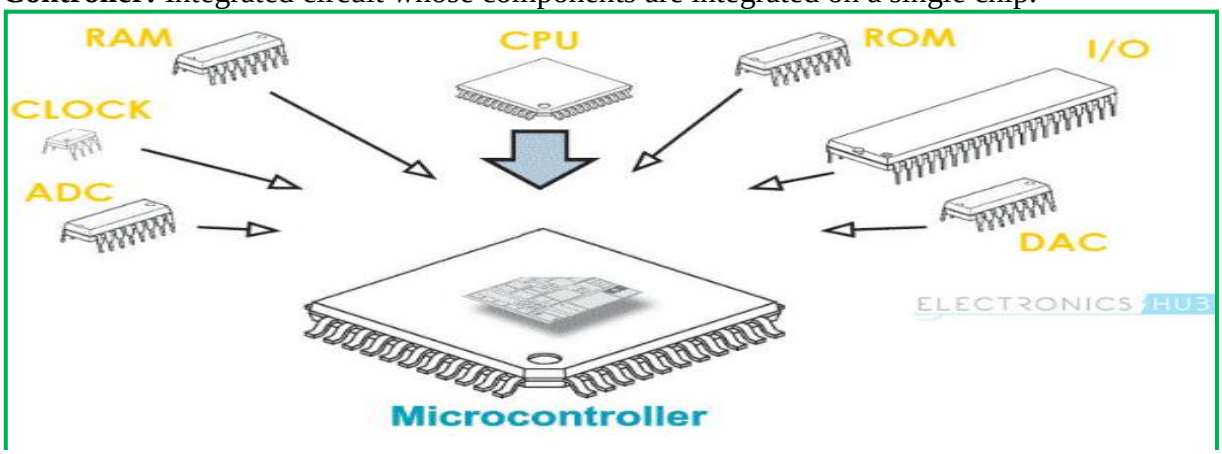


Sensors

- Sensor is mainly used to capture part of the existing data, correlate and synchronize these data, analyze them, and finally, carries out a reactive activity without user intervention.

SENSOR	FUNCTION	APPLICATION
Electrochemical	Use of electrodes to detect specific ions in the soil	For determining the NPK content of soil
Optical	Use of light to measure soil properties	Photodiodes and photo- detectors to determine moisture content of soil
Mechanical	Use of probes to measure soil compaction or mechanical resistance	Irrigation
Dielectric Soil Moisture	Use of electrodes to assess moisture levels by measuring the dielectric constant in the soil	To sense soil water content

Microcontrollers / Computer-on-a-Chip or a Single-Chip-Computer / Embedded Controller: Integrated circuit whose components are integrated on a single chip.



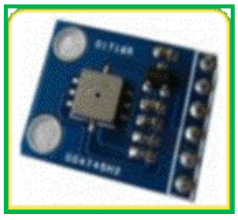
Temperature and Humidity Sensor

Soil Moisture Sensor

pH Sensor

Soil Moisture 200SS Sensors

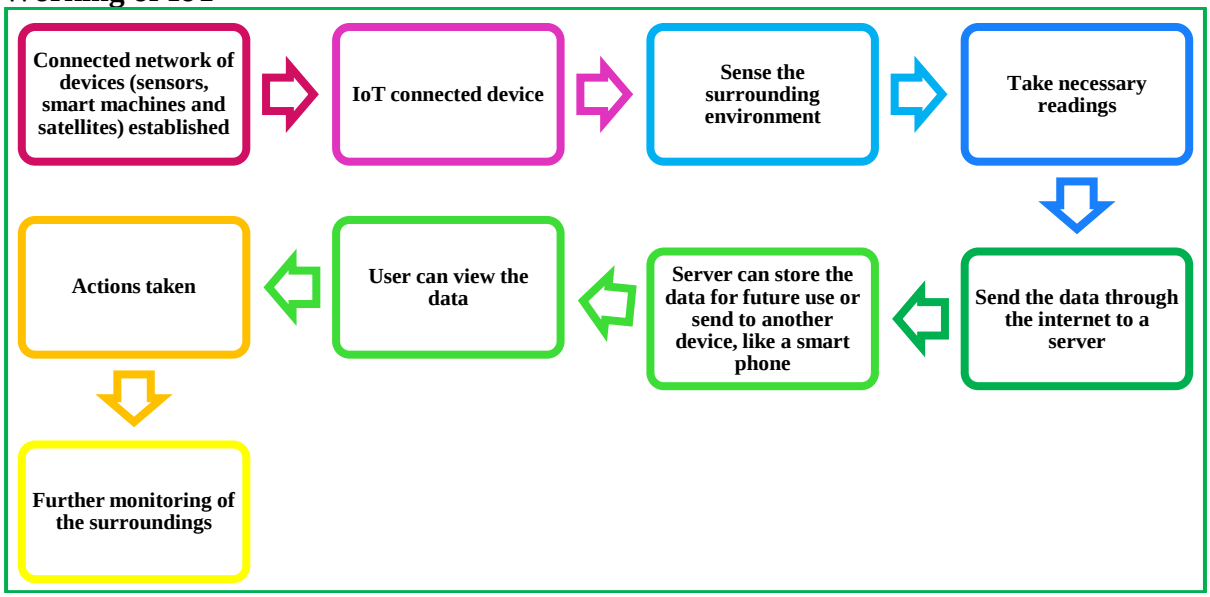
Soil EC Sensor



Soil NPK Sensor

Barometric Pressure Sensor

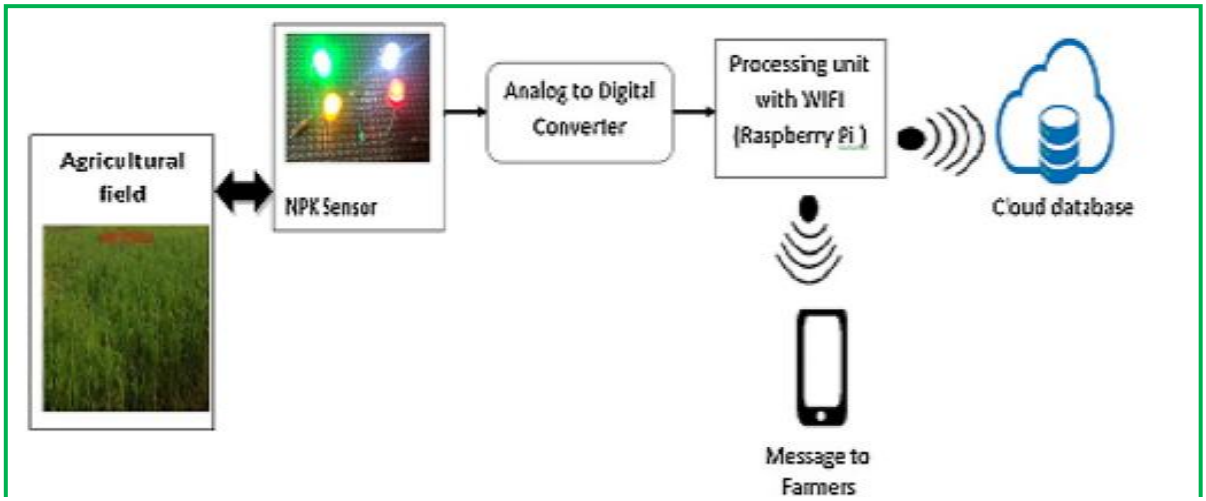
Working of IoT



Soil Monitoring with IoT

- Measuring the soil moisture content
- Monitoring the soil temperature
- Assessing pH levels and chemical composition

IoT based Fertilizer Intimation System



- Measurement of N, P, K contents of soil relies on colorimetric measurement of solution of soil.
- The colour of a substance is present due to the absorbance of waves of bound wavelengths.
- The absorption of light ends up in excitation of electrons in its molecule.
- The colour detector is based on the principle of absorption of color.
- It helps in determining the N, P, K amounts as high, medium, low, or none.

Soil Sensors

Indigenously developed at IIT Bombay

Gives the solutions for optimized irrigation for agriculture

Soilsens= soil moisture sensor + soil temperature sensor + ambient humidity sensor + ambient temperature sensor

Solar powered system

Can be used across all crops and all soils

Benefits of IoT in soil and water

1. Benefits of IoT based Smart Irrigation System

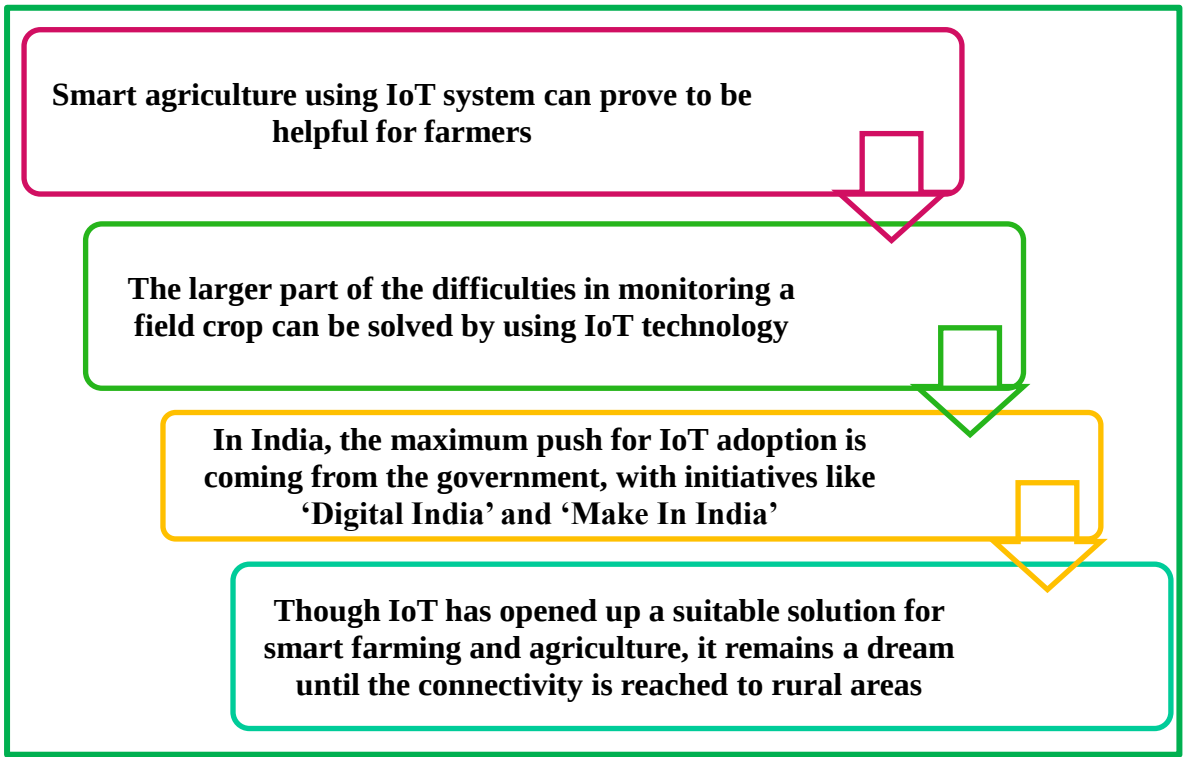
- Avoids over and under use of water in irrigation.
- Help the farmers to monitor the water tank levels in real-time.
- Allows to save water by detecting leaks quickly and exactly.
- Reduces the wastage of water
- Can be a solution to labour shortage problem.

- Can be implemented in large agricultural areas.

2. Benefits of Soil Monitoring Using IoT

- Determining which areas need fertilizer and which don't.
- Help to decide the quantity of the fertilizer required
- Help to understand how parameters like fertilizer brand, quality of the soil and the crops being grown have affected the production over the years.

IoT uses



Technology tools used for SSNM

- Global Positioning System (GPS)
- Geographic Information System (GIS)
- Remote Sensing (RS)
- Crop Manager/Nutrient Manager
- Nutrient Expert
- Laser Land Levelers
- Leaf Colour Chart (LCC)
- Green Seeker

Global Pointing System (GPS): Most of the tools for precision agriculture involve use of data collection or controller systems that utilize the global positioning system (GPS). Each set of data collected is associated with its specific geographic coordinates (latitude, longitude, and elevation). This allows the understanding of precise relationships among the different layers of data, the resulting yield data, and other measurements. These layers can then be analysed to make recommendations for future decisions. GPS systems are used on planting equipment for collecting geo-referenced planting data, starter fertilizer application, and other inputs. With proper controllers, variable-rate application of inputs can be added to the management plan. Each of these steps can be added over time, increasing the value of the initial investment. As more advanced military-technology becomes available for public use and new technologies develop to support GPS, this tool will continue to become more valuable to farmers in implementing site-specific management.

Geographic Information System (GIS)

- Geographic Information Systems (GIS) consist of data and software designed for spatial analysis of GPS referenced data.
- Various databases in an agricultural GIS system might include soil survey data, soil test information, pest infestations, yield data, remote sensing imagery and other types of observations and records that can be collected and referenced with their geographic position (by GPS).
- These data sets can then be converted to maps to illustrate their spatial variability within the field and become additional layers in the field database.
- The capability of GIS is more than mapping.
- By using models integrating the different spatially-variable data sets, responses to inputs can be predicted, or interactions affecting yield can be identified.
- Accumulated over time, the GIS data sets become increasingly useful as record-keeping and prediction tools.

Remote Sensing

- Remote sensing is becoming a useful tool for precision farming, using scanners on aircraft or satellites to monitor changes in wavelengths of light from fields and growing crops.
- The data collected can be mapped and analysed with the help of GIS tools, to provide additional data layers for GIS analysis and management decisions.
- It is used to document such issues as pest problems, weather factors, nutrient management issues, and more. While it has taken several years to develop remote sensing technology to the point of providing dependable, cost effective products and services in a timely fashion, there are now such services available to add to the toolbox to aid farmers and their advisors in making crop management decisions.

Application of Remote Sensing in Agriculture

- Crop water stress detection
- Diagnosis of nutrient deficiency
- Agro metrological information
- Crop production forecasting
- Vegetative indices
- Used to detect weed or insect pressure in an area

Crop Manager / Nutrient Manager

- The Nutrient Manager is nutrient decision support tool accessible through the web browser on computers and smartphones for nutrient recommendation to rice crop in irrigated or rainfed lowland environments, based on input users.
- The Nutrient manager is designed to help extension workers, farmers and other beneficiaries to quickly formulate fertilizer best management for rice crop. The tool consists of 10–15 questions i.e. easily answered by the farmer. On the basis of responses to the questions, the fertilizer guidelines with fertilizer dose required by crop growth stages are provided for the rice field from users.
- Crop Manager for Stress-Tolerant Rice (CMSTR), Rice-Wheat Crop Manager (RWCM), and Rice Maize Crop Manager (RMCM) developed by IRRI.

Nutrient Expert

- Nutrient Expert (NE), a nutrient decision support tool, is developed by International Plant Nutrition Institute (IPNI) following the principles of 4R Nutrient Stewardship and site-specific nutrient management (SSNM). Nutrient Expert is interactive and rapidly provides

crop and site-specific nutrient recommendation in the presence or absence of soil testing data.

- Nutrient Expert predicts the attainable yield and yield response to the fertilizer from site information using decision rules developed from on-farm trials (Pampolino *et al*. 2014).

Leaf Colour Chart

- Leaf colour charts (LCC) offer substantial opportunities for farmers to estimate plant nitrogen (N) demand in real time for efficient fertilizer use and high rice yields.
- Asian farmers generally apply fertilizer N in a series of split applications, but the number of splits, amount of N applied per split, and the time of applications vary substantially.
- The apparent flexibility of rice farmers in adjusting the time and amount of fertilizer application offers potential to synchronize N application with the real-time demand of the rice crop.

Biochar – A Sustainable Input

Biochar is a carbon-rich material that is made from biomass through a thermochemical conversion process known as pyrolysis Some common feedstocks include the following:

- Food waste
- Municipal solid waste (MSW)
- Plastics
- Sewage sludge (also known as "bio-solids")
- Agricultural by-products
- Cuttings and trimmings from parks and residence

The nutrient retention of biochar

- Some researches indicated that incorporation of biochar into soil effectively reduced N_2O emission from different soils. For instance, Rondon *et al.* (2005) reported that 50 % reduction of N_2O emissions was found under soybean systems while 80 % decrease of N_2O emissions was found for grass systems.
- Biochar made from Lantana *camara* at 300 °C contained available P (0.64 mg kg^{-1}), available K (711 mg kg^{-1}), available Na (1145 mg kg^{-1}), available Ca (5880 mg kg^{-1}), and available Mg (1010 mg kg^{-1}) (Masto *et al.* (2013).

Sea Weed Extract

- In recent times seaweeds received worldwide attention as organic/bio-fertilizers to supplement plant nutrients
- It is known that heavy metal ions such as cadmium and lead are successfully removed using seaweed biomass as adsorbents. Hence the seaweed could be scientifically exploited as adsorbents and by virtue of macroscopic structure facilitate the successful production of biosorbent particles suitable for biosorption.
- Seaweeds could be successfully used to ameliorate the salt stress affecting the plant growth. Because of high salinity in marine environment seaweeds exposed to continuous slat stress and under this hyperosmotic conditions' compounds such as proline, betaines, polyamines and sorbitol are synthesized and accumulated at high concentrations which are closely associated with salt stress tolerance in seaweeds.

Soil Conditioners

- **Organic soil conditioners**: Intensive agriculture is producing an enormous amount of agricultural by-products, which could be considered as a great option in soil conditioning for sustainable agricultural productions. Plant origin wastes have long been transformed into soil conditioners For instance, spent mushroom compost (SMC) has been applied to enhance soil OM and nutrient contents in agricultural land

- **Industrial waste-based soil conditioners**: Industrial by-products can also be useful for sustainable agricultural productions. For instance, liming and sewage sludge compost effectively improves soil health and plant growth Hygienic bio digestate and fibre sludge can be effective fertilizers in light of nutrient contents
- **Synthetic soil conditioners**: Polymers are typical synthetic soil conditioners, which can be used at a low rate to achieve cost-effectiveness. Apart from improving the soil physical properties, polymeric organic materials and hydrogels can act as buffers against short-term drought stress and improve the crop establishment For example, the effectiveness of Polyacrylamides on the soil moisture retention and growth of plants have been extensively examined
- **Commercial products of soil conditioners**: There are a vast market for soil conditioners because of their effectiveness. Currently, there are numerous types of commercial products available in the market. They could be of natural and synthetic origins depending on the products they are made of. e.g. Seaweed + fish + humate

Hydrogels

- Hydrogels (super absorbent polymers) are three dimensional, cross linked hydrophilic polymers that can imbibe large amount of water or biological fluids.
- In agricultural field, hydrogel is used for increasing the amount of available moisture in the root zone and for improving soil physical properties which includes water holding pores, bulk density, porosity, structural stability, infiltration rate and hydraulic conductivity.
- As a controlled release formulation, the functionalized polymers can be also used for enhancing the absorption of nutrients by plants.
- They are also used to increase the efficiency of pesticides and herbicides by releasing lower dose at a time thus protecting the environment

Carbon Nano Tubes

- A **carbon nanotube** (**CNT**) is a tube made of carbon with diameters typically measured in nanometers. Such tubes were discovered in 1952 by Radushkevich and Lukyanovich
- The relative abundances of phosphate-solubilizing microorganisms increased after exposure to single-walled carbon nanotubes (SWCNTs), which was beneficial for phosphorus bioavailability in the soil.
- MWCNTs can be potentially applied in agriculture to improve the Nitrogen Use Efficiency of plants.

Microbial Consortia

- Microbial consortia have more properties than an individual microbial inoculum, due to the synergy of the microorganisms that populate them.
- Increased microbial biodiversity stabilizes the functioning of agro-ecosystems and increases the resilience to climate change

Conclusion

In conclusion, the advancements in soil fertility management, driven by precision agriculture, IoT technologies, and sustainable inputs, hold significant promise for enhancing agricultural productivity while ensuring environmental sustainability. Embracing these trends will be crucial for addressing the challenges faced by modern agriculture and achieving long-term food security.

References

1. Dobermann, A. and White, P.F. (1999) Strategies for nutrient management in irrigated and rainfed lowland rice systems. In: Balasubramanian, V., Ladha, J.K., Denning, G.L.

(eds) Resource Management in Rice Systems: Nutrients. *Developments in Plant and Soil Sciences*, vol **81**. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-5078-1_1

2. Pampolino, M. F., Witt, C., Pasuquin, J. M., Johnston, A. and Fisher, M. J. (2014) Development and evaluation of the Nutrient Expert decision support tool for cereal crops. Better Crops-South Asia **8**(1), 4–6. https://link.springer.com/chapter/10.1007/978-981-13-5904-0_2
3. Masto, R.E., Ansari, M.A., George, J., Selvi, V. and Ram, L. (2013) Co-application of biochar and lignite fly ash on soil nutrients and biological parameters at different crop growth stages of *Zea mays*. *Ecological Engineering* **58**, 314–322.
4. Rondon, M., Ramirez, J. and Lehmann, J. (2005) Charcoal additions reduce net emissions of greenhouse gases to the atmosphere. In: *Proceedings of the 3rd USDA Symposium on Greenhouse Gases and Carbon Sequestration in Agriculture and Forestry*, Baltimore, MD, p. 208.