INDIAN SOCIETY OF SOIL SCIENCE
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MESSAGE

Soil is the soul of infinite life. It is the most wondrous gift of nature to human society. Without soil, there is no life on the planet Earth. One spoon of a healthy soil contains more than billions of microorganisms of different species. Soil is the place where food begins. It is the reservoir of plant nutrients that play a critical role in the production of food and feed for the ever-growing global population. Soil organisms are responsible for nutrient transformations that are required to produce food. For optimum utilization and protection of soil resources in the global food system, policies and strategies to develop nutrient-efficient management as well as raising awareness regarding the importance of maintaining healthy soil, healthy ecosystems and human well-being are the need of the hour.

Considering the importance of soil, the Indian Society of Soil Science (ISSS) came into existence way back on December 22, 1934 with only 30 members in the Physical Chemistry Laboratory, University of Calcutta (now Kolkata). It was formally inaugurated on January 3, 1935 at the Presidency College, Calcutta. Sir B.C. Burt, the then Agricultural Commissioner in the Imperial (now Indian) Council of Agricultural Research, was the first President of the Society and Prof. J.N. Mukherjee its first Secretary. The ISSS is the oldest professional society among the various disciplines of agricultural sciences in India. The headquarter of the ISSS was shifted to the then Imperial (now Indian) Agricultural Research Institute (IARI), New Delhi in 1945 and functioned at the Division of Soil Science and Agricultural Chemistry till 2008. Then it was shifted to its current office at the National Agricultural Sciences Centre (NASC) Complex, Dev Prakash Shastri Marg, Pusa Campus, New Delhi. Presently the ISSS has more than 2750 members with 53 Chapters spread across the country to serve as a forum for the soil scientists of a region in India to meet, discuss, and take steps to achieve the objectives of ISSS, with particular reference to the region and also to assist the main body of the ISSS to further the causes of Soil Science.

It gives me immense pleasure that the Kolkata Chapter of the Indian Society of Soil Science is regularly publishing the Newsletter highlighting the contemporary issues on soil-plant-animal-human health written by its members of eminence as well as displaying the different activities of the Kolkata Chapters. On this occasion, I congratulate the Kolkata Chapter of the Indian Society of Soil Science for the release of their next issue of the Newsletter. On this occasion, I and extend my best wishes for successful publication of the same.

Dipak Ranjan Biswas
President

Article 1: Agriculture, Energy and Sustainable Development: An Integration

Introduction

The philosophical perception of integration is the interdependence between function and its variables. In agriculture, plants, energy and sustainable development are interlinked with each other and they are interdependent. In achieving the sustainable development goals (SDGs), it is projected that by 2050 the world population will reach about 9.8 billion which will demand 65% more food, 58% more water, 80% more energy with reference to today's consumption. In bringing the tomorrow's food security there is a need for thrust in the agriculture sector in conjunction with achieving SDGs.

Agriculture is the backbone of rural economy in the developing world and this needs for manpower with updated knowledge in enriching / enhancing the agricultural productivity for developing food security. The water and energy are the two integral parts of agriculture and they form a nexus at the center of SDGs. It is reported that the food and agriculture sectors are consuming about 80-86% of the world's freshwater and 30-36% of world's energy. It is further reported that both agriculture and energy sectors are responsible in emitting greenhouse gasses (GHGs) to the atmosphere.

Demand on supply for three items like water, food and energy, as mentioned previously, is increasing rapidly and to meet the current demand as well as the to withstand future pressures, there should be an integrated approach on sustainable management of water, food and energy to balance the needs of people, nature and the economy. The pressure on water, food and energy nexus is being driven by a rising global population, rapid urbanization, changing diets and economic growth. There is a significant global move away from a mainly starch-based diet to an increasing demand for more water-intensive meat and dairy products due to increased incomes in many countries.

In addressing SDGs thrust must be given on increasing and in developing clean and safe energy resources. There needs to be much more support for the development of less water-intensive energy conversion systems, such as solar photovoltaic (PV), wind and hydrogen. Hydrogen (H_2O) normally extracted from water (H_2O) and biowastes. After energy conversion H_2 again react with oxygen (O_2) and formed oxides of H_2 as H_2O balancing the resources. Geothermal energy has great potential as a long-term, climate independent resource that produces little or no greenhouse gases and does not consume any water. The sustainable agriculture is critical one and the integrated systems of land, soil and water are being stretched to the breaking point. The system efficiency measures along the entire agrifood chain can help in saving water and energy, such as precision irrigation / drip water based on information supplied by water providers, and protection of ecosystems alongside agriculture and energy production can ensure environmental integrity. The ecosystems must be valued for their vital services. There should be thrust in harnessing the power from nature instead of allowing its destruction and degradation in the pursuit of food and energy. The 'Green infrastructure', such as land dams to capture runoff in arable fields or planting forests to protect soil and assist groundwater recharge, are some examples of creating a more sustainable water-food-energy nexus and a 'greener' economy. Integrated management of water-food-energy must be a top priority in achieving SDGs. Because of this nexus, crucial role in many SDGs, decision-makers in all three domains must cooperate on water resource management, ecosystem protection, water supply and sanitation.

Agriculture is one of the sectors that are heavily dependent on energy and at present coming from fossil fuels. The energy from fossil fuel not only jeopardizes food security but also poses significant risks to its SDGs and production. Conversion of fossil fuel for energy conversion and food processing lead to emission of greenhouse gases (GHGs) in the environment. The Intergovernmental Panel on Climate Change (IPCC) reported that agricultural and food-chains alone consume about 30% of the world's total energy. Furthermore, because of the high consumption, this accounts for about one-third of annual GHG emissions.

The increasing demand for food and the industrial revolution in agriculture has necessitated a higher energy supply. On the other hand, the environmentally harmful effects of fossil fuels have increased the importance of using renewable energy technologies in the agricultural sector. However, the individual use of such energies might not be sufficient.

Agriculture and Energy

Energy from renewable sources is mainly derived from solar radiation, wind, water, tides, waves, and geothermal sources. Among these, the energy from solar radiation has a high potential for use in rural and remote areas. Solar energy is normally converted in two routes and these are i. Thermal and ii. Electrical. In thermal route solar radiation is converted into heat through thermal conversion devices and is used for heating and drying purposes. On the other hand, electrical conversion is done through PV conversation systems. The electrical power from PV system can be used in standalone mode as well as it can be blended in grid and exported in meeting the peak demand. The PV conversion needs large land, about five acre per megawatt. The solar PV power plants can be installed over the mounting structure on the agricultural land surface and that land surface can also be used for agricultural purposes. The system is known as 'Agrivoltaic' and it proposes the dual use of land for energy and food security purpose. Moreover, installation PV power plants over the land surface reduce the surface evaporation rate that decrease the water demand and introduce water conservation opportunity. The solar PV power sometimes inducts 'Electrokinetic' effect on the soil surface and enhances the soil fertility also.

The 'Agrivoltaic' systems not only provide the energy and food security from the same land but also help in obtaining spin-off supports like physical pesticide systems. This, in turn, drives out the insects from the planted areas which impose detrimental effects in agriproducts through energizing UV and blue LEDs.

Implementation of 'Agrivoltaic' systems introduces the landowner benefits in the form of lease payments from the system operators to the landowner, which is especially the case for wind turbines and other land-intensive energy technologies. The 'Agrivoltaic' systems at the road side can generate employment opportunity in setting up 'Electrical Charging Stations' for charging the electrical vehicles from PV power plants which are installed over the agricultural land.

Although there are several studies on the use of renewable energy in agriculture, a thorough evaluation considering the three important aspects of technology, economics, and policy and regulation is essential.

The agricultural wastes sometimes are used in energy production. The waste biomasses in rice and jute processing industries can also be used in energy conservation measures. The waste biomasses can be the gasified into synthetic fuel gas or syngas which contain 18-22% of CO, 8-12% of H_2, and 3-4% of CH_4. Rest is CO_2, N_2 and H_2O. Both rice and jute processing industries have the captive diesel generators for meeting the demand for additional load and support during load shedding time. The integration of syngas from biomass gasifier to the captive diesel generator can conserve diesel fuel. Detailed studies in several rice mill indicated that rice husk gasifier can conserve 70-72% of diesel fuel when the generator is running in 80% load. The biomass gasification further produces charcoal that can be used for various industrial activities as well as smokeless fuel pellets. Integration of these has major impact in rural economy, ecology and empowerment.

Agriculture and Emission

The energy use in agriculture and food security (AFS) is heavily dependent on fossil fuels-based energy conversion systems which are the major source for emission of GHGs. Thus, in terms of reducing the emission of GHGs, there are opportunities to analyze by examining the contribution of agricultural practices to current emission levels. The IPCC reported that agriculture sector plays an important role in GHG emissions with the highest contribution of 55% and 45% for methane (CH_4) and nitrous oxide (N_2O), respectively in crop production. In addition, the gut fermentation is the largest source of CH_4 production in agricultural systems, while manure is the second most important stimulus for the release of CH_4 and N_2O. Artificial nitrogen-based fertilizers, as the third participant accounting for 13-15% of GHG emissions, release N_2O gas when microbes begin to process residual nitrogen from crops.

As mentioned earlier, the 'Agrivoltaic' systems have the potential to reduce water demand and increase the overall water productivity of certain crops. Studies conducted on the growth characteristics of tomato plants at different locations in an Agrivoltaic field / park observed greater water productivity in interrow treatments than that in the control deficit, and that total crop yield decreased with increasing shade. These results indicate the potential of PV systems to improve water productivity even in crops traditionally considered shade intolerant.

An important feature of the modern agriculture is greenhouse cultivation, in which the growth of plants is controlled to obtain better yields in quantity and quality. The promising results of PV modules provide the required electrical energy and ensure sufficient crop production. However, the shading effect led to a reduction in crop yield as the photosynthetic efficiency of greenhouse plants decreased. It was also shown that photovoltaic-thermal modules (which produce both electrical and thermal power at the same time) are interesting due to the generation of electrical and thermal energy from a single module with high efficiency. It was demonstrated that the use of these solar technologies in greenhouses can increase the quantity and quality of the crop productions.

Concluding remarks

For the introduction of new technologies, the investors need to be knowledgeable about the technology and its outcome. Development and investment in new technologies require encouragement and support from various sectors like educational institutions, financial organizations and the governance. Doubts can be cleared removed through training, seminars, conferences, participation in projects, and information campaigns. The educational institutions can take a major role in this aspect. In addition, training can provide the necessary skills, including those needed to install, set up, and maintain systems, and create a skilled workforce in rural as well as in urban areas.

Projecting the future demands for food and the onset of mechanization in agriculture, there is need to address concerns about the energy security, while the spin-off sources should be explored for developing 'Zero Energy' systems. The renewable energies have the biggest potential for their use in agricultural sector. At the same time agriculture sector can be the sources for supply energy resources. Power from agricultural wastes like rice husk, stubble, and dry leaves can be converted into synthetic fuel gas through gasification of biomass, and this can be used in conserving diesel fuels while operating in dual fuel mode. Apart from energy conservation opportunities, there are the concerns about the environmental impacts of conventional energy suppliers and this highlights the importance of using renewable technologies in the agricultural sector, which provides the impetus for an energy transition toward renewable energy. Applications of machine power instead of muscle power in agricultural activities brought several benefits. The implementation of solar-powered irrigation systems, tractors and agricultural robots offer opportunities for energy savings and reducing hazardous emissions. Due to their higher initial cost, promotion of these faced problems in penetrating into the market. Implementation of sensors in drip irrigation for water management / conservation is another emerging area for taking water conservation measures. These not only enrich the agriculture sectors but also encourage the implementation of artificial intelligence (AI) and robotic technologies through machine learning (ML), thereby opening up the new paths for further exploration in agricultural sectors. Nevertheless, the 'Agrivoltaic' will certainly open up new avenues to the future researchers with reference to achieving integration of agriculture with sustainable development goals.

Biswajit Ghosh

The Neotia University
Sarisha, D. H. Road, 24 Paragons(S),
email: bghosh3@gmail.com

Article 2: Eco-restoration for people, nature and climate

The 2030 Agenda for Sustainable Development seeks to end poverty, conserve biodiversity, combat climate change and improve livelihoods for everyone, everywhere. These objectives, encapsulated in 17 Sustainable Development Goals (SDGs) are unlikely to be met unless ecosystem degradation is stopped and ecosystem restoration is undertaken at the immense scale of hundreds of millions of hectares globally. Currently, there is insufficient political support and technical capacity in both the public and private sectors to invest in the many hundreds of thousands of ecosystem restoration initiatives worldwide that are needed to achieve restoration at such a scale.

The world is facing severe challenges. Billions of people around the world are suffering the consequences of the climate emergency, food and water insecurity. Ecosystems are an indispensable ally as we meet these challenges. Protecting them and managing their resources in a sustainable manner is essential. But just increasing the protection and sustainable management of our remaining natural landscapes and oceans will not be enough: the planet's degraded ecosystems and the huge benefits that they provide must also be restored.

By declaring the UN Decade on Ecosystem Restoration, governments have recognized the need to prevent, halt and reverse the degradation of ecosystems worldwide for the benefit of both people and nature. The 2021–2030 timeline underlines the urgency of the task. Without a powerful 10-year drive for restoration, we can neither achieve the climate targets of the Paris Agreement, nor the Sustainable Development Goals.

We can no longer deny that we are a part of our environment, which we are degrading at an alarming rate. In order to embark on a more sustainable pathway, we need both to conserve and restore ecosystems. This report makes the case for why restoration, in particular, is so important and outlines how the UN Decade can catalyze a movement to restore the world's ecosystems.

Healthy, stable and biodiverse ecosystems are the foundation of our health and well-being, as well as that of our fellow species. They help to regulate our climate and control extreme events, pests and diseases, as well as to provide us with water, food, raw materials and spaces for recreation. They absorb our wastes, sustain economic sectors and the livelihoods of millions of people, and they nurture our health, culture and spiritual fulfilment. We have been overexploiting and degrading the world's ecosystems and wild species, causing the erosion of the very services we depend on (UNEP 2021). The global economy has seen incredible growth over recent decades–growth that has been fueled by the erosion of the world's natural assets. Thus, our massive gains in income and poverty reduction come at the expense of a significant deterioration of the health of the biosphere. We are using the equivalent of 1.6 Earths to maintain our current lifestyle (Global Footprint Network 2021) and are putting the future of our economies at extreme risk.

Ecosystem restoration is the process of halting and reversing degradation, resulting in improved ecosystem services and recovered biodiversity. Ecosystem restoration encompasses a wide continuum of practices,depending on local conditions and societal choice. Restoration of Ecosystems can follow different trajectories: From degraded natural ecosystem to more intact natural ecosystem (often by assisting natural regeneration); From degraded, modified ecosystems to more functional modified ecosystems (e.g. restoration of urban areas and farmlands); From modified ecosystems towards more natural ecosystems, providing that the rights and needs of people who depend on that ecosystem are not compromised.Countries need to deliver on their existing commitments to restore 1 billion hectare of degraded land and make similar commitments for marine and coastal areas.

Unfortunately, we are still going in the wrong direction. Ecosystem restoration is must on a large scale. Everyone has a role to play in ecosystem restoration. We are degrading our ecosystems in serious ways. From farmlands to forests, from mountains to oceans, our diverse ecosystems – both natural and modified – are being damaged faster than they can recover.

In all ecosystems, biodiversity loss and degradation are caused by direct drivers (land- or sea-use change, direct exploitation, climate change, pollution, and invasive species), which are underpinned by demographic and economic indirect drivers that interact in complex ways. While the specific causes of degradation vary across ecosystems, in general overfishing is having the greatest impact on oceans, and terrestrial and freshwater ecosystems are most affected by land-use change, which is driven mainly by agriculture, forestry and urbanization.

The declaration of 2021-2030 as the UN Decade on Ecosystem Restoration is purposeful and hopeful, bearing in mind the unsettling revelations of landmark scientific findings of the state of our biosphere. It reveals that this decade matters most in preventing catastrophic climate change and bending the curve on biodiversity loss, without which an estimated 1 million species face the threat of extinction, many within decades.

While there is some momentum on a global response to the threats of climate change, it is imperative that human action is rooted in restoration of the world's degraded and destroyed ecosystems. With a window for action becoming ever so small, in halting and reversing the trends of biodiversity loss and ecosystem degradation, the UN Decade hopes to inspire a global movement, a generation for restoration.

As long as ecosystems are not degraded, they are a source of wealth for society. Healthy ecosystems, whether they be forests, rivers and lakes, oceans and coasts, mountains, grasslands and peatlands, or farmlands and urban landscapes, provide us with ecosystem services, the numerous benefits that humans and other life forms gain from a well-functioning ecosystem. These include benefits such as food, fibre, medicine, climate regulation, water purification, fresh air, and aesthetic value.

Ecological restoration-an identifiable way to tackle the global disease burden and improve public health. Ecological restoration is a clear and identifiable way to tackle the global disease burden. Climate change, ecological degradation and biodiversity loss have cascading knock-on effects on human health and well-being. Deforestation and extinction of species will make pandemics more likely (Study of more than 6,800 ecosystems across six continents provided further evidence). Ecosystem damage also leads to water contamination, creating breeding grounds for infectious diseases.

10 years to restore our planet. 10 actions that count are the following.

- Empower a Global Movement
- Finance Restoration on the ground
- Set the Right Incentives
- Celebrate the Leadership
- Shift Behaviours
- Invest in Research
- Build up a Capacity
- Celebrate the Culture of Restoration
- Build up the Next Generation
- Listen and Learn

Scaling up ecosystem restoration activities assumes national importance as: India holds four of the world's 12 mega biodiversity hotspots of the world. It accounts for nearly 8% of the recorded species, which includes 47,000 plant species and over 100,000 animal species; over 10,000 plant species have medicinal properties. India with 2.4% of the world's land area, supports 18% of the global human population and accounts for 15% of the world's livestock.

The UN Decade on Ecosystem Restoration is a global call. To reimagine, recreate and restore the balance in nature, restore our sources of livelihood, our health and our quality of life. Individuals have an integral role to play in ecosystem restoration through right lifestyle choices and raising public awareness on its importance. Ecosystem restoration requires everybody's participation. Regenerative is an integral part of Ecorestoration and it is beyond Conservation Agriculture aiming at: maintaining continuous vegetation cover on the soil as much as possible; stabilization of organic matter on soil mineral complexes; increasing the amount and diversity of organic residues returned to the soil; restoring microbial life essential to soil health and biodiversity. With current rates of soil destruction, within 50 years we will suffer serious damage to public health due to a qualitatively degraded food supply. Without protecting and regenerating the soil on our 4 billion acres of cultivated farmland, 8 billion acres of pastureland, and 10 billion acres of forest land, it will be impossible to feed the world, keep global warming below 2 degrees Celsius, or halt.

Regenerative agriculture aims at increasing the amount of organic carbon added back into the soil while reducing the relative loss from erosion (C) and soil respiration (CO_2).

For annual croplands, these practices include: (i) reduced tillage/no-till and cover crops, (ii) diverse crop rotations with higher frequency of perennial crops (iii) grass cover for waterways and crop buffers (iii) agroforestry (e.g. hedgerows, windbreaks, tree cropping), (iv) conversion of marginal lands, not suited for annual crops, to perennial plantings *vis-a-vis* industrial crops, and (v) utilization of compost and organic waste to build soil health.

Six Major Steps are to be taken for regeneration of the ecosystems

1. Managing soil fertility by enhancing SOM content N fixation and nutrient recycling
2. Improving soil structure (activity and soil biodiversity)
3. Increasing bioavailability of green water by reducing losses
4. Controlling water and wind erosion

(continuous ground cover)

5. Managing soil acidification and elemental inbalance by biofertilizer
6. Increasing water infiltration rate by phyto-physical methods

The Green Revolution of the 21st century based on the concepts of Ecorestoration and Regenerative Agriculture must be:

Soil-based, through enhancement and sustainable management of soil health by managing SOM content.

Ecosystem-based, through enhancement of eco-efficiency that minimize loss-more efficiently.

Knowledge-based, by using modern science and managerial skills.

Based on 'Law of Return (Howard,1943)' replenishing what has been used.

Focused on creating a positive soil ecosystem C budget so that the terrestrial C pool is increasing over time.

Since the 1950s humanity has made enormous advances in health, poverty reduction and economic development. However, those gains have come at a massive ecological cost (Dasgupta, 2021). Between 1992 and 2014, we doubled the per capita value of produced capital (roads, machines, buildings, factories and ports) and slightly increased the value of human capital (health and education), while the value of stock of natural capital (specifically, minerals and fossil fuels, agricultural land, forests as sources of timber and fisheries) fell by a staggering 40 per cent.

Restoration of ecosystem plays a significant role in food security, clean water, human health and well-being. Agroforestry alone has the potential to increase food security for 1.3 billion people (Smith et al. 2019), and can reduce soil erosion by 50 per cent and increase soil carbon by 21 per cent, inorganic nitrogen by 46 per cent and phosphorus by 11 per cent (Muchane et al. 2020)

Restoring wetlands and riverine areas can improve water quality by capturing pollutants and sediment from land degradation. The Itaipu hydroelectric dam in Brazil now benefits from sediment control by restored areas upstream, thanks to a programme that encourages farmers to create terraced fields and reforest river banks. Ecosystem health is interconnected with both physical and mental human health. We rely on ecosystems to regulate the climate, prevent disease and provide natural spaces in which to exercise and lower stress levels. They are also a source of ingredients for both traditional medicine and biomedical and pharmaceutical development (WHO and CBD, 2015).

To avoid catastrophic climate change, 2030 should mark two milestones: the end of the UN Decade on Ecosystem Restoration and the achievement of emissions reduction targets in line with the Paris Agreement goal to limit global warming to below 2°C. Delaying this will push us past a tipping point, beyond which solutions will be less effective- and some damage, irreversible (IPCC, 2018)

That we are altering the climate by continually emitting GHGs into the atmosphere is an inescapable reality (IPCC, 2014). But ecosystem restoration can play an important role in people's adaptation to climate change by increasing resilience and reducing vulnerability to extreme events.

Humanity now faces a choice:

We can continue down a path where our demands on Nature far exceed its capacity to meet them on a sustainable basis, or

we can take a different path, one where our engagements with Nature are not only sustainable but also enhance our collective well-being and that of our descendants.

Let us make peace with nature as: Man is a part of nature, and his war against nature is inevitably a war against himself

DD Patra

Former Vice Chancellor, BCKV, Mohanpur, West Bengal

Article 3: Agriculture 5.0: Managing Soils with Sensors and AIML

1. *The Plight of Conventional Soil Testing in India*

Soil is one of the most important but neglected components of the ecosystem. A multitude of environmental, biotic, and pedogenic factors continually interact in a complex, orderly manner, which causes variation in soil properties. Consequently, spatial variability characterization and classification of the soil physicochemical properties and their complex relations are of prime concern. The great demand for increased food productivity without exploring new areas under native vegetation has become a strong focus of agriculture in recent decades. In this context, precision agriculture has played an important role by optimizing productivity and raising land use efficiency through the assessment of spatial variability of soil properties, including nutrient contents. Regarding the spatial variability of soil nutrients, precision agriculture promotes a viable way to identify and delineate critical nutrient deficiency zones. Thus, it is possible to determine areas demanding variable management practices, e.g., the variable-rate application of fertilizers and ameliorants, and defining management zones.

Indian agriculture is challenged with feeding an increasing population with limited land and water resources. A long-term decline in soil health due to unsustainable agricultural practices and environmental management currently threatens the continued delivery of these critical ecosystem services, which has prompted researchers to place greater focus on properties related to soil health. Soil testing is an important step in increasing agricultural production and raising farm income. Traditional soil testing methods are based on chemical methods carried out under laboratory conditions. These methods are generally time-consuming (several days to months for routine soil parameters), costly (~Rs. 400 per sample), tedious, and involve elaborate sample preparation steps. On the other hand, the number of soil samples that needs to be analyzed is large because of the small size of the landholdings in many parts of India. Consequently, even if soil samples are collected from different agricultural fields, timely testing of these samples is generally not possible, and the test results often fail to reach farmers on time. This initiates a negative feedback loop creating a strong aversion to soil testing among our agricultural community.

2. *What is Agriculture 5.0?*

"Agriculture 5.0" is a term that refers to the future of agriculture, which is expected to be characterized by a more connected, data-driven, and sustainable approach to farming. The term "Agriculture 5.0" follows the evolution of agriculture through several stages, from the first Agricultural Revolution (Agriculture 1.0) to the present day (Agriculture 4.0), where precision agriculture, automation, and the use of big data are already common.Agriculture 5.0 is expected to build on these technologies and trends to transform the agricultural sector further. It will leverage the advancements in technologies such as artificial intelligence (AI), robotics, the Internet of Things (IoT), and blockchain to create a more efficient, sustainable, and resilient agricultural system (Fig. 1).

One of the key features of Agriculture 5.0 is the use of data-driven decision-making. Farmers will collect data on soil quality, weather patterns, plant health, and other factors using sensors and other IoT devices, and use this information to make informed decisions about planting, fertilization, irrigation, and pest control. AI and machine learning (AI/ML) algorithms will analyze this data to provide personalized recommendations and predictions to farmers.Another key feature of Agriculture 5.0 is the increased use of automation and robotics. Autonomous tractors, drones, and robots will perform tasks such as planting, harvesting, and monitoring crops, reducing labor costs and increasing efficiency. Finally, Agriculture 5.0 will prioritize sustainability and environmental responsibility. Farmers will use precision agriculture techniques to reduce waste and optimize resource use, such as water and fertilizers, and will focus on regenerative practices to improve soil health and reduce greenhouse gas emissions. Overall, Agriculture 5.0 promises to revolutionize the way we produce food, increasing efficiency, sustainability, and resilience in the face of climate change and other challenges facing the agricultural sector.

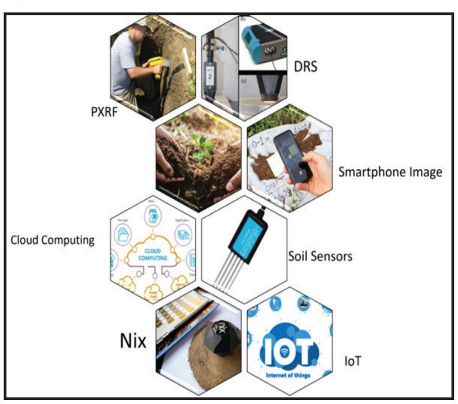

Fig.1. Components of a smart soil characterization system

3. *Real-time Soil Sensing*

Researchers have long struggled with an effective method for quantifying soil health, especially considering the large number of chemical, physical, and biological indicator measurements needed to accurately assess soil health, for which specific needs and methods may vary by region and soil type, and the time and labor costs associated with this approach. Real-time soil sensing is a key component of precision agriculture, which involves using technology to optimize crop production. By monitoring soil properties such as moisture content, nutrient levels, and pH in real-time, farmers can make informed decisions about irrigation, fertilization, and other factors that affect crop growth and yield. Furthermore, real-time soil sensing can help farmers conserve resources such as water and fertilizer. By monitoring soil moisture levels, for example, farmers can avoid over-watering their crops, which can lead to water waste and runoff. Similarly, by monitoring nutrient levels, farmers can avoid over-fertilizing their crops, which can lead to nutrient pollution in nearby waterways. Notably, real-time soil sensing using various sensors and AI/ML can help farmers save money by optimizing their use of resources such as water and fertilizer. By avoiding over-watering and over-fertilizing, farmers can reduce their input costs while still maintaining high crop yields. It can also help protect the environment by reducing the amount of fertilizer and pesticides that are applied to crops. By monitoring soil properties and only applying inputs when and where they are needed, farmers can minimize the impact of these chemicals on the environment.Summarily, sensor-based approaches have the potential to provide a cost-effective, site-specific solution for rapid soil health monitoring and management. Soil sensors with wireless connections in the fields can continuously monitor soil moisture, temperature, pH, electrical conductivity, and salinity.

4. *Artificial Intelligence for Soil Management*

Artificial intelligence has the potential to revolutionize soil management by enabling more precise and sustainable agricultural practices. AI/ML is increasingly being used in soil management to improve agricultural productivity and sustainability. Here are some of the ways AI/ML is being applied in soil management:

a) Digital Soil Mapping: AI/ML can be used to create high-resolution digital maps of soil properties such as texture, organic matter content, and pH. These maps can be used to identify areas of the field with different soil properties and tailor management practices accordingly.

b) Predictive Modeling: AI/ML can be used to develop predictive models of soil properties and crop growth based on historical data and environmental factors. These models can help farmers make informed decisions about planting, fertilization, and other management practices.

c) Precision Farming: AI/ML can be used to guide precision farming practices such as variable-rate fertilization and irrigation. By analyzing real-time data from sensors and other sources, AI algorithms can adjust inputs to optimize crop growth and minimize waste.

d) Decision Support Systems: AI can be used to develop decision support systems that help farmers make informed decisions about soil management practices. These systems can provide real-time recommendations based on current and historical data, as well as environmental factors such as weather forecasts.

5. *Internet of Things (IoT) for Soil Management*

The Internet of Things (IoT) has the potential to revolutionize agriculture by providing real-time information on various factors that affect crop growth, including soil health. Currently, IoT has been utilized in the following applications of soil science:

a) Soil moisture sensors: IoT-enabled soil moisture sensors can be installed at different depths in the soil to monitor moisture levels. This information can be used to optimize irrigation and prevent over-watering, which can lead to water wastage and crop damage.

b) Soil nutrient sensors: IoT-enabled soil nutrient sensors can be used to monitor the levels of nutrients such as nitrogen, phosphorus, and potassium in the soil. This information can be used to determine the right amount of fertilizers to use and to prevent nutrient imbalances, which can affect crop yield.

c) Soil temperature sensors: IoT-enabled soil temperature sensors can be used to monitor soil temperatures. This information can be used to optimize planting schedules and prevent planting in soil that is too cold or too hot for optimal crop growth.

d) Soil pH sensors: IoT-enabled soil pH sensors can be used to monitor soil pH levels. This information can be used to adjust soil pH to the optimal level for the crops being grown.

e) Smart irrigation systems: IoT-enabled smart irrigation systems can be used to optimize irrigation by automatically adjusting watering schedules based on real-time weather and soil conditions.

Overall, IoT can be used to provide farmers with real-time information on soil health, allowing them to make data-driven decisions that can optimize crop growth and yield while minimizing water and fertilizer usage.

6. *Emerging Sensors for Rapid Soil Characterization*

Emerging proximal sensor technologies such as diffuse reflectance spectroscopy (DRS) and portable x-ray fluorescence spectrometry (PXRF) can efficiently quantify soil salinity, total C/total nitrogen, and other soil properties. PXRF is a non-destructive analytical technique that is used to determine the elemental composition of a material. The technique involves using a handheld instrument to shoot low-energy (10-40 keV) X-rays at a material, which causes the atoms in the material to emit characteristic fluorescent X-rays that can be detected and analyzed.The PXRF instrument consists of an X-ray source (typically a miniaturized X-ray tube or radioactive source), a detector, and associated electronics. The X-rays produced by the source are directed at the material of interest, and the resulting fluorescent X-rays are collected by the detector. The incident X-ray forcibly ejects inner shell electrons of matter. The specific energy identifies the element and the strength of emission enables quantification *via* silicon drift detector. In other words, PXRF measures the energy of the emitted fluorescent X-rays, which allows it to identify the elements present in the material.This analysis can be done in the field, on-site, in 60-90 sec with little to no sample preparation needed. PXRF is widely used in a variety of applications, including environmental analysis, geology, archaeology,and forensic science. It is particularly useful for analyzing materials in the field or on-site, as the instrument is portable and can be used without the need for sample preparation or destruction.

Diffuse reflectance spectroscopy (DRS), on the other hand, is a non-destructive analytical technique used to study the properties of a material by measuring the amount of light it reflects at different wavelengths. Unlike traditional reflectance spectroscopy, where light is reflected at a specific angle and direction, DRS measures the amount of light reflected at all angles. In DRS, a sample is illuminated with a broadband light source, and the reflected light is measured using a detector. The amount of light reflected at each wavelength is then analyzed to determine the properties of the sample, such as its chemical composition and physical structure. DRS is commonly used in the analysis of powders like soil, fibers, and other solid materials, and it has applications in fields such as chemistry, soil science, materials science, and biology. It is particularly useful for studying samples that are opaque or highly scattering, as it can provide information on their internal structure without the need for additional sample preparation.

PXRF analysis has been successfully applied for elemental quantification of soil. Beyond direct reporting of total elemental concentration of plant essential nutrients and heavy metals (e.g., Pb, Cd, Cr, As, etc.), PXRF-based elemental data, combined with various regression techniques have been used to determine soil pH, salinity, cation exchange capacity, soil texture, gypsum content, calcium carbonate development, lithologic discontinuities, and base saturation percentage. Studies have been conducted on natural soils, mine tailings, and areas affected by heavy metal pollution. Newer approaches have extended the application of PXRF to land use/land management characteristics, compost, vegetation, and water analysis. Coupled with georeferencing, the combined use of DRS+PXRF can predict multiple soil properties in a single day on-site with non-destructive scans.

Visible near-infrared diffuse reflectance spectroscopy (VisNIR-DRS) is a technique that combines the visible and near-infrared (NIR) regions of the electromagnetic spectrum to analyze the properties of a material. The technique is similar to traditional DRS, except that it uses a light source that covers both the visible and NIR regions of the spectrum.The visible region of the spectrum covers wavelengths between 400 and 700 nanometers (nm), while the NIR region covers wavelengths between 700 and 2500 nm. VisNIR-DRS can provide information on both the chemical composition and physical properties of a material, such as its moisture content, particle size, and color. VisNIR-DRS have many applications, including the analysis of soil components. It is also used in remote sensing, where it can be used to identify and map the mineral content of soils and rocks from a distance. One advantage of VisNIR-DRS is that it is non-destructive and requires little or no sample preparation, rendering it a fast and efficient technique for analyzing a wide range of materials. Additionally, VisNIR-DRS can be used for both qualitative and quantitative analysis, making it a versatile technique for a variety of soil applications. Notably, VisNIR-DRS technique has achieved wider acceptance in soil science, owing to its cost-effectiveness and advantages over other analytical spectroscopic and wet chemistry methods.

Among other technologies, Smartphone images can be useful for soil analysis, especially when combined with appropriate software and analytical tools. By taking a close-up image of the soil surface using a smartphone camera, texture analysis software can determine the size distribution of soil particles and classify the soil as sandy, loamy, or clayey.The color of soil can be an indicator of its composition, organic matter content, and nutrient availability. Using a smartphone camera, images of soil samples can be captured and analyzed using color analysis software to determine the soil color and its corresponding chemical properties.Moreover, nutrient content in soil can be analyzed using smartphone images by capturing images of soil samples and applying machine learning algorithms to detect and quantify nutrient deficiencies or excesses.By capturing images of soil samples using a smartphone camera and applying image processing techniques, soil moisture content can be estimated. Overall, smartphone images can be a useful tool in soil analysis, especially for field-based measurements where laboratory analysis is not feasible or practical. Several smartphone apps are available for soil analysis. For example, SoilWeb is a free app that provides access to USDA-NRCS soil survey data for the United States. The app allows users to identify their location on a map and view soil survey data for their area, including soil types, properties, and limitations. Moreover, Soil Test Pro is a paid app that allows farmers and agronomists to collect, manage, and analyze soil test data. The app includes features such as soil sampling recommendations, real-time GPS mapping, and customizable reports.Soil Doctor is a free app that provides soil analysis and fertilizer recommendations based on the user's location and crop type. The app allows users to take a picture of their soil sample and submit it for analysis, and then provides customized fertilizer recommendations based on the results. Furthermore, Plantix is a free app that uses artificial intelligence and machine learning to diagnose crop diseases, nutrient deficiencies, and pest problems. The app includes a soil analysis feature that allows users to analyze their soil pH, nitrogen, phosphorus, and potassium levels, and provides recommendations for fertilization. Among other apps, SmartSoil is a paid app that allows users to analyze soil moisture, temperature, and nutrient levels using a smartphone sensor. The app provides real-time data and alerts, as well as customized soil management recommendations. However, it is important to note that using smartphones for soil analysis requires appropriate software and analytical tools, as well as proper calibration and validation of the results.

The Nix color sensor is a handheld device that can be used for soil analysis. The device measures the color of a soil sample and provides a corresponding analysis of soil properties, such as nutrient content and organic matter. This sensor allows for non-destructive testing of soil samples, which means that the same sample can be tested multiple times without damaging the soil.The device is simple to use and does not require any specialized training. The user simply needs to place the sensor on the soil sample and press a button to obtain a color reading.Nix uses advanced colorimetric technology to provide accurate results for soil analysis. The device is capable of detecting subtle color variations in soil samples that may not be visible to the naked eye.Nix is a compact, handheld device that can be easily transported to remote locations for field-based soil analysis.Notably, this sensor has been used for a variety of soil analysis applications, including determinin`g soil texture, identifying nutrient deficiencies, and estimating organic matter content.

7. *Future of Sensor - based Soil Characterization in India*

There is a growing awareness among farmers and policymakers in India about the importance of soil health for sustainable agriculture. This has led to an increased demand for soil testing services and technologies.Sensor-based soil testing is a cost-effective alternative to traditional laboratory-based testing, which can be expensive and time-consuming. This makes it more accessible to small and marginal farmers in India.The devices are easy to use and do not require specialized training or technical expertise. This makes them more accessible to farmers in remote and rural areas.The Indian government has launched several initiatives to promote soil health and sustainable agriculture, including the Soil Health Card Scheme, which provides farmers with information on the nutrient status of their soil. This has created a demand for soil testing services and technologies in the country. Overall, the future of sensor-based soil testing in India looks promising, as there is a growing need for accurate and cost-effective soil analysis to support sustainable agriculture and improve farm productivity.

Somsubhra Chakraborty

Associate Professor, Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur

Article 4: Cluster based entrepreneurship development approach through vermicomposting technology among farm women

In recent days, increasing concern regarding utilization of different organic composts in semi-urban, urban and rural areas are getting more importance and everybody is thinking for improving soil health and crop quality. Considering the soil health, economic return and environmental footprints, farming community are becoming more inclined towards the utilization of agricultural wastes through composting techniques and find a new additional means of income generation. Due to the increasing cost of cultivation, as a result of high price of fertilizers, seeds, agro inputs and decline in soil-water-plant health, farmers now understand the importance of compost application in their agricultural management practices. In addition, the consumption of good and quality compost by urban population for their gardening practices is gaining momentum. Thus, the commercial production of compost is now becoming a profitable venture to the farmers and rural youths. Generally, the cow dung or farm yard compost is prepared by the farmers in a very unscientific way resulting in production of very poor quality compost. In rural areas, more than 60% of total available cow dung is utilized for making cow dung cakes for fuel purpose as the process is easy and economically profitable. Remaining part of the cow dung is used for poor quality compost preparation by only dumping method in an open pit or chamber under the sun. Furthermore, the produced compost is broadcast in the field by just heaping or dumping for long time leading to loss of nutrients through the action of water (percolation loss) and sun (evaporation loss). Among the different composts prepared from the green wastes, animal excreta or agricultural residues, vermicompost is the best option in respect of nutrient source and economic profitability for entrepreneurship development. In rural areas, the production of vermicompost includes the uses of local unidentified earthworm species or unscientific methods of compost production that results in low production and economic benefit. Basically, the bottleneck of the adaptation of vermicomposting technology to most of the farmers is due to lack of proper scientific knowledge and technical skills about composting process in respect of compost quality and productivity.

In this regard, intensive extension activities of Sasya Shyamala Krishi Vigyan Kendra (SSKVK) regarding awareness and build up of technical skills for proper utilization of agricultural wastes by producing vermicompost has made a considerable impact in different villages of three Blocks of South 24 Parganas district of West Bengal. Before conducting the demonstration activities, KVK primarily assessed the scenario of the vermicomposting technology in different villages and Blocks of South 24 Parganas district of West Bengal and took an initiative for popularizing the vermicomposting technology to the farmers of four villages (Moushul, Andulgaria, Sheoraberia) of Bhangar I and Majherpara village of Canning II Block of the district). It was observed that the demand of vermicompost in these areas was very high, but compost utilization has not become common due to unavailability of the compost. To develop awareness and technical skill, a number of awareness-cum-training programmes were organized by SSKVK. For the purpose dissemination of the waste utilization technologies, vermicomposting was taken as the lead technology to fulfill three objectives of demonstration - enhancing income generation, compost production and increasing crop yield with higher productivity and reduced cost of cultivation.

For gearing up the knowledge and skill of the farmers, a number of trainings, group discussions, farm clinic etc. were organized for vermicompost production in scientific way followed by demonstration in their villages during 2019-2021. After assessing the technical knowledge gap, farmer's interest and skills of the farmers, total 32 numbers of farmers, farm women and rural youths were selected as beneficiaries form the villages and one vermicompost unit was developed for each of them in their own household with the financial support from ICAR-ATARI and ICAR-NBSSLUP, Kolkata Regional Center during 2019 to 2021. In addition, the horizontal expansion of the composting technology to the villages was also monitored to assess the success of the technology dissemination.

Table 1. Knowledge gaps regarding the traditional composting process by the farmers

Sl. No.	Common Practice	Lack of information	Improvement of the knowledge after KVK interventions
1.	Heaping of cow dung	Turning of cow dung for proper decomposition of organic material	Regular turning of cow dung for preparation of pre-decomposed earthworm feed
2.	Only cow dung as feed	Green materials can increase compost quality	Incorporation of agricultural green waste for composting
3.	Local earthworm variety	Specific variety of earthworm for vermicomposting	Uses proper earthworm variety i.e. *Eudrilus eugeniae*
4.	No management during composting	No idea of optimal conditions (feed quality, temperature, moisture content, aeration and bedding materials) for better growth of earthworms	Maintaining the quality feed preparation, supply of bedding material, moisture and temperature conservation
5.	Earthworm collection by sieving	Sieving can harm earth worm health, population and eggs	Improved techniques for collection of earthworm

Establishment of vermicompost demonstration units:

One cemented tank (Length = 8 feet, Width = 4 feet, Height = 2 feet) for vermicomposting was established for demonstration purpose in the beneficiaries' household. The internal slope of 1% with an outlet in the tank floor was maintained to collect the vermiwash properly. The shades of the units were developed by the beneficiaries at their own cost. Each beneficiary was given one kilogram of matured earthworm sp. *Eudrilus eugeniae* (African Night Crawler) for vermicomposting process.

Adaptation of scientific composting processes:

The common practice of vermicomposting process included the exclusion of pre- decomposition of cow dung, use of only cow dung, absence of turning of the composting materials followed by direct incorporation of earthworms to the cow dung. This approach significantly reduced the quality of compost, production rate of compost and reproduction rate of earthworms. It was unknown to the farmers that green biomass of aquatic plant (water hyacinth, water cabbage) and pseudo stem of banana can be efficiently utilized for vermicomposting process. The compost production with KVK intervention ensured the incorporation of these locally available wastes with cow dung to improve the compost quality and productivity. Initially 7-10 days' old cow dung was properly mixed with different agricultural wastes (water hyacinth, *Pistia Stratiotes Linn,* mushroom waste straw, pseudo banana stem, green gram husk, weed waste, etc.) in 3:1 ratio and kept for pre-decomposition for 15-20 days. The incorporation of the green materials helped to increase the NPK and microbial population of the vermicompost in comparison to the sole cow dung vermicompost. Turning of the composting material regularly was followed to increase aeration, minimize the temperature and expel out gases (NH_3, CO_2, N_2O, H_2S etc.). After that earthworms (@25-30 nos./sq. ft.) were added in the feed and covered with wet gunny bags to maintain the moisture and temperature. During the composting process, they maintained the moisture content as per the requirement and compost was harvested approximately within 55-60 days. As per the technical guidance from KVK, they efficiently harvested the earthworms by "feed ball" method. They continued the composting process for two times annually per unit by using the produced earthworms successfully.

Successful production of vermicompost and vermiwash

It has been observed that the beneficiaries are now producing vermicompost @ 4.5-6.5 quintal and 110-135 l of vermiwash and 1.5-2.0 kg of earthworms per unit annually. Initially they used minimum quantity of compost, but now 15-18% of the produced vermicompost was utilized in their own cultivation with an increase of 22-25% of the compost use. The remaining portion of the compost was marketed with increasing demand to the local farmers. Some of them purchased their produces for large-scale marketing to the outside buyers. KVK has promoted the linkage between farmers and different NGOs, agrifarms and dealers through different extension activities. They have reduced their inorganic fertilizer requirement to the tune of 16-18% with an effective adaptation of compost utilization.

Witnessing the production improvement and economic profit from the utilization of vermicompost in farming practices and marketing of the compost respectively, large number of farmers and farm women in these areas showed intense interest that was very encouraging. During this period, 35 farm women adopted this enterprise successfully by starting the compost production in plastic drums, over the plastic sheet and plastic bag simultaneously along with the tank method. Besides, use of quality organic manure like vermicompost by the farmers increases the quality and quantity of different crop production and improves soil health in the long run. Now their feedback regarding the production of healthy vegetable seedlings from compost enriched seedbed and reduced inorganic fertilizer demand can be considered as a sign of successful venture for improving soil health, utilization of agricultural waste management and income generation.

Economic benefit:

It was observed that this cluster based vermicomposting approach significantly helps to improve annual income of Rs. 5,000- 6,500.00 per unit by marketing of vermicompost @Rs. 12-15.00/kg, vermiwash @ Rs. 20.00/l and earthworms (@ Rs.1600-1800.00/kg. The annual pooled production of vermicompost comes to approximately 14-16 t with total income of Rs.1.92-2.15 lakh. Thus, the cluster-based vermicompost production approach showed a potential scope for entrepreneurship development resulting in women empowerment in these villages.

Conclusion

It was observed that the promotion of vermicomposting technology not only generates awareness regarding the benefit of compost use, but also generates an additional income to the beneficiaries which helped in horizontal dissemination of the technology to the farmers and farm women. The availability of good quality vermicompost also helped to improve the soil health as well as the crop yield which also increased the interest of the farmers to avoid the practice of cow dung cake production as fuel and increased the vermicompost production at commercial scale. The increasing adoption of the vermicompost production by farm women helped to strengthen women empowerment through entrepreneurship development.

Figure 1. Training and practical demonstration on vermicomposting technology at village level by Sasya Shyamala KVK

Figure 2. Vermicompost production in plastic drum unit and using of earthworms (Eudrilus Eugeniae) for composting

Figure 3. Vermicompost and earthworms (Eudrilus Eugeniae) production for composting

Figure 4. Successful production of vermicompost for marketing purpose

Monidipta Saha[1], Narayan Chandra Sahu[2] and F. H. Rahman[3]
[1,2]Sasya Shyamala Krishi Vigyan Kendra, RKMVERI, Sonarpur, Kol-700150
[3]ICAR-ATARI, Kolkata 700097

Article 5: Nutrient Mining in Indian Agriculture and Food Security *vis-a-vis* Soil Health Issues

1. Introductory Remarks

The necessity of increasing food production to meet the demand of the ever-increasing population in India hardly requires any over-emphasis. Estimates suggest that at the current level of production, an additional 5 to 6 Mt food grain has to be added each year to the national food basket for the next decade or so to feed the increasing population. The total area under cultivation remains more or less constant (at 140-142 Mha) over the past several decades, and there are indications that the agricultural lands are gradually being diverted to accommodate increased urbanization and industrialization. It is unlikely that sizable additional area will be brought in under cultivation in the foreseeable future. Therefore, there is no other viable option than increasing crop productivity per unit area, to meet the future production goals. Maintenance of native soil fertility in the intensively cultivated regions of the country is one of the preconditions of maintaining and improving the current crop yield levels. Intensive cropping systems remove substantial quantities of plant nutrients (especially of potassium, compared to its consumption in the country) in many cases from soil during continued agricultural production round the year. The basic principle of maintaining the fertility status of a soil under high intensity crop production systems is to annually replenish those nutrients that are removed from the field. Indeed this becomes more relevant in the absence of the measures for adequate replenishment of the depleted nutrient pools through the removal of crop residues from agricultural fields (Sanyal 2014). One would use the term "**Nutrient Mining**" when the quantity of soil nutrients removed by a crop from an agricultural field exceeds the amount of the nutrient that is recycled back and/ or replenished to the field. Nutrient mining (which is of primary relevance in respect of potassium in the Indian context*; see later*) causes a decline in the native soil fertility and may seriously jeopardize future food security of the country. Unfortunately, the concern for nutrient mining in Indian soils is largely limited to the scientific community and has not been integrated adequately with the crop production practices (Sanyal *et al*., 2014; Majumdar *et al*., 2016).

2. Imbalance in Fertilizer Application in India

Balanced fertilization in India is

often accepted as N, P_2O_5 and K_2O application in the ratio of 4:2:I (Figure 1). The validity of such a uniform prescription across the board, without taking into account the inherent features of the soil and the type of crop grown, has been questioned at different forum, The NPK fertilizer application is highly skewed in favour of nitrogen over the past several decades. Indeed there *cannot* be a single, *all pervading ratio* that can justify the concept of balanced fertilization. Doubtless, such a concept of a uniform fertilizer application schedule would be in direct ***conflict*** with the very principles of the site-specific nutrient management **(SSNM)** as well as **precision agriculture**. Furthermore if one takes a look at such ratios of NPK fertilizer applications in different countries around the globe, there is hardly any such definite NPK ratio of fertilization practice. In our country, ideally an all-India indicator of the desired balanced fertilizer application should emerge as a weighted average of the state or *even* the agro-ecological zone level indicators while going beyond the realm of NPK only (Sanyal *et al*. 2009). Whatever may be the origin of 4:2:1 ratio, farmers in India do ***not*** follow it under most farm situations (Figure 1). The application of N fertilizers tends to be preferred by farmers, obviously owing to their relatively low cost per unit of nutrient (due to Government subsidy), their widespread availability, as well as the quick and evident response of the plant. The universality of the principles of the SSNM approach has led to its application to different crops and agro-ecologies (Majumdar *et al*. 2016). The in-built algorithms of SSNM cut down the over- and under-use of fertilizers and significantly reduce the probability of K management in soil-crop condition. So conceptually moving from a generalized nutrient management approach, based on some arbitrary ratio, to a rational site-specific approach would be a point of addressing the nutrient mining (particularly of K) issue and hence help arresting the decline of native soil fertility. The Fertiliser Consumption (NPK) and Ratio of Fertiliser Application Ratio over 2015-16 to 2019-2020 is given in Table 1.

Table 1. Fertiliser Consumption (NPK) and Ratio of Fertiliser Application Ratio over 2015-16 to 2019-2020

Year	Consumption Ratio	All India Total Consumption of N,P_2O_5 & K_2O (000 tonne)			Total Consumption (t)
		N	P_2O_5	K_2O	
2019-20	7.0 : 2.8 : 1	18,796.90	7,543.10	2,698.90	29,038.90
2018-19	6.6 : 2.6 : 1	17,637.80	6,910.20	2,680.30	27,228.30
2017-18	6.1 : 2.5 : 1	16,959.30	6,854.40	2,779.70	26,593.40
2016-17	6.7 : 2.7 : 1	16,735.90	6,705.50	2,508.50	25,949.90
2015-16	7.2 : 2.9 : 1	17,372.30	6,978.80	2,401.50	26,752.60
2014-15	6.7 : 2.4 : 1	16,949.60	6,098.90	2,532.90	25,581.40

Source: Sanyal and Majumdar (2021)

In this context, it is distressing to note that about 292 (out of 600+) districts account for consumption of 85 per cent of all of the country's fertilisers. Besides, there are discrepancies in the use of fertilisers on the basis of chemical ratios. The current consumption ratio of nitrogen, phosphorus and potassium (NPK) is 6.7:2.4:1 against the (so-called) "ideal" ratio of 4:2:1.***The situation is grimmer in the major agricultural states like Punjab and Haryana where NPK use ratios are as high as 31.4:8.0:1 and 27.7: 6.1:1, respectively*** (Sanyal and Majumdar, 2021).

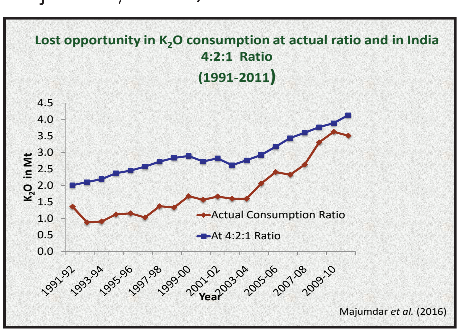

Figure 1. Lost opportunity in K_2O consumption at actual ratio and in India 4:2:1 Ratio (1991-2011)

Source: Majumdar et al. (2016)

3. Potassium Mining from Soil: Negative Nutrient Balances in Cropping Systems

Indeed, continuous cropping with only N and P application, without any or inadequate K application may lead to substantial depletion of the reserve (non-exchangeable potassium, NEK, pool) K in soils (Sarkar *et al*. 2013, 2014), and more importantly, this would go largely unnoticed as per the conventional soil test for plant available K. This may prove alarming for the sustainability of the dominant cropping systems as well as those including the K-loving crops, *e.g.,* potato The non-exchangeable K (NEK) reserve in soil is classified into two categories, namely step-K and constant-rate K (CR-K), as being respectively the one (step-K) which contributes slowly to the plant-available pool of soil K on a long-term basis, and the one (CR-K) which is much less amenable to supply K to crops under K stress,

Furthermore the native soil K status depends, not only on the parent material of soil, but also on the subsequent stages of weathering of the parent material. Hence the weathering history of a mineral phase, rather than its mere presence, may be an important factor to be reckoned while relating the plant availability of soil K to the soil mineralogy (Sanyal and Majumdar 2001). An example of such postulate is provided by a sharp contrast between an Entisol and an Alfisol under rice-based cropping system in West Bengal. Thus, there was a wide variation in total K and non-exchangeable K contents of these soils despite almost the same amount of potassium-bearing illite content in these soils (Sanyal and Majumdar, 2021). This is obviously linked to the relative stages of weathering of the illitic mineral phase in the given soils. Such observations need to be taken into account, while making the fertilizer K recommendations to support the different cropping systems practiced in these soils. The aavailable K estimation may not reveal K mining (mining of non-exchangeable potassium) as shown in Figure 2.

Ghoragacha, West Bengal

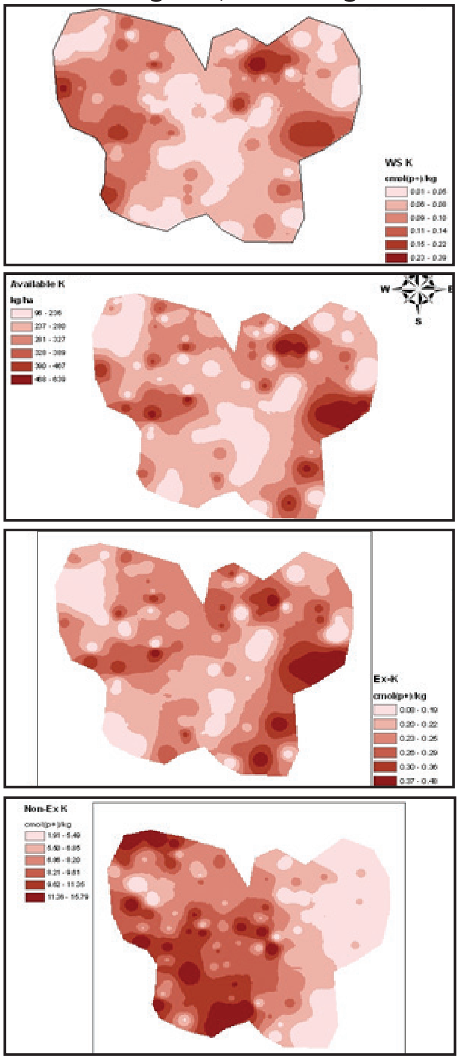

Figure 7, Available K estimation may not reveal K mining (in a rice-based cropping system in West Bengal)

Source: Chatterjee *et al*. (2015)

4. Soil Fertility Fatigue in Intensive Agricultural Scenario in Irrigated Soils (IGP) in India

While noting the **declining partial and total factor productivity (suggesting decline in native soil fertility as well as crop productivity)** (Figure 2), one would be inclined (intuitively) to conclude that the decline in crop productivity would be accompanied by the decrease in soil organic carbon (SOC). However, **e**vidence from the long-term experiments have shown that application of nutrients at optimum rates either increased or maintained the SOC due to greater incorporation of biomass (Benbi and Brar 2009). Thus, the reported fatigue or decline in productivity in the Indo-Gangetic Plains (IGP) is ***not*** always accompanied by the decline of SOC (due to global warming). This may well indicate that the decline in the productivity in the IGP does not arise from the oft-believed declining trend of the SOC status due to the prevailing global warming effects. In fact, Bhattacharya *et al*. (2007) noted an overall increase in SOC stock at the Benchmark spots, located in the IGP and the Black soil (Vertisols) region in the semi-arid tropics, between 1980 and 2005. These authors also noted an increase in the level of soil inorganic carbon (SIC), which, they suggested, implies an initiation of chemical degradation of the soil. This probably means that the decline in the fertiliser factor and total factor productivity in these soils, particularly in the IGP, has a direct bearing on (among others) the mining of essential plant nutrients, overwhelmingly of potassium (as stated above), rather than indirectly through nutrient management effects on SOC content of the soil (Sanyal *et al.,* 2014). Large body of experimental evidence are now available that showed under-performance of soils when soil fertility levels are downgraded due to over-extraction and under-application of nutrients.

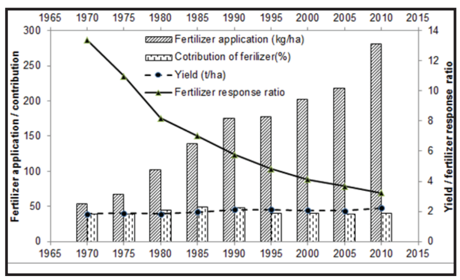

Figure 2. Response and contribution of fertilizer in food grain production in irrigated areas over the years in India

Source: Chaudhari *et al.* (2015)

5. Economics of Potash Application in Cereals, Pulses and Oilseed Crops in the Indo-Gangetic Plains

It is well known that India does not have any muriate of potash (MOP) deposit and as a result the soluble potassic fertilizer, based on MOP, is to be imported. This would add to the cost of cultivation. This is one of the contributory factors for the farmers to apply no and/or inadequate K-fertilizers in India. However, as observed by Majumdar (2017—Unpublished data), judicious application of potassic fertilisers in this country may turn to cost- effective, or even profiteering cultivation of important cereal crops (Table 2) as well as pulses and oilseeds (Table 3).

Table 2. Economics of Potash Application in Cereals in the Indo-Gangetic Plains

Economics of Potash Application in Cereals in the Indo-Gangetic Plains

Crop	Yield No K kg/ha	Yield with K kg/ha	K Rate kg K_2O/ha	Yield Increment kg/ha	Value of increased production Rs.	Return per Re. I invested in K
Rice	4,080	4,701	60	621	6210	5.5
Wheat	4,373	5,096	100	723	8459	4.5
Maize	5,644	6,343	100	699	6151	3.3

Rice :45 trials, MSP: Rs. 10/kg Wheat: 141 trials, MSP: Rs.11.7/kg Maize :7 trials MSP: Rs. 8.8/kg
K_2O Price: Rs. 18.83/kg

Source: Majumdar (2017-Unpublished data)

Table 3. Return on Investment (ROI) for K Fertilizer in Oilseeds & Pulses at Different Crop Response Levels & Application Rates

Return on Investment (ROI) for K Fertilizer in Oilseeds & Pulses at Different Crop Response Levels & Application Rates

Yield Response Classes of Oilseeds (kg/ha)	275	381	600
Application Rate	ROI Oilseeds (Rs /Re)		
25 kg K_2O/ha	10.3	14.2	22.4
50 kg K_2O/ha	5.1	7.1	11.2
75 kg K_2O/ha	3.4	4.7	7.5
Yield Response Classes of Pulses (kg/ha)	**76**	**137**	**312**
Application Rate	**ROI Pulses (Rs /Re)**		
20 kg K_2O/ha	4.6	8.2	18.7
40 kg K_2O/ha	2.3	4.1	9.4
60 kg K_2O/ha	1.5	2.7	6.2

Prices: Potash = Rs.30/kg K_2O Average MSP of Oilseeds = Rs.28/kg of grain
Average MSP of Pulses = Rs. 36/kg of grain

Source: Majumdar (2017-Unpublished data)

6. Critical Assessment of Field Specific Nutrient Input- Output Balance

Nutrient input-output balance in an agricultural field is one of the most critical knowledge requirements for implementing the aforesaid SSNM. Nutrient balance studies are common in literature.The following example from Buresh *et al*. (2010) illustrates the methodology; followed in estimating K balances in agricultural fields for single crop as well as cropping systems involving cereals. The essential components of such K balance calculations included contributions (inputs) from the retained residues, irrigation water and added organic matter and loss (output) of K from the system through leaching and export through the grain of the component crops. Buresh *et al*. (2010) used the following equations to estimate the K balance in continuous rice, rice-wheat and rice-maize cropping systems:

K balance for rice = $K_W + K_{OM} + K_{CRr} - K_L - (GYr \times RIE_{Kr})$ ...[1]

Potassium balance for rice–wheat or rice–maize = $K_W + K_{OM} + K_{CRr} + K_{CRwm} - K_L - (GYr \times RIE_{Kr}) - (GYw \times RIEKwm)$ ....[2]

Where K balance and each input are expressed in kg ha^{-1}, K_W is K input from irrigation water for an entire cropping cycle, K_{OM} is K input from the added organic materials, K_{CRr} is K input with the retained residues of rice, K_{CRwm} is K input with the retained residues of wheat or maize, K_L is K loss by percolation or leaching in kg ha^{-1}, GYr and GYwm are the targeted grain yields in t ha^{-1} for rice and wheat or maize, RIE_Kr is the reciprocal internal efficiency of rice for K , and RIE_{Kwm} is the reciprocal internal efficiency of wheat or maize for K. The K input from residues for a crop (K_{CR}) was determined from the amount and the nutrient content of the above-ground crop biomass retained in the field after harvest using the following equation:

$K_{CR} = GY \times RIE_K \times (1 - HI_K) \times CRR$ ...[3]

Where HI_K is the K harvest index for a crop, expressed as kg nutrient in grain per kg nutrient in total above-ground dry matter, and CRR for a crop is the fraction of the total crop residue retained in the field after harvest. The results from this study suggested that retention of rice residues in continuous rice-rice systems is a **must** for maintaining a positive K balance in the soil. The K balance was found to be positive only at 100% residue retention even at an assumed K addition of 20 kg ha^{-1} through irrigation water (Buresh *et al*. 2010). However, the K balance was strongly negative at 15-40% of residue retention, which is indeed the prevailing situation in India. Rice-wheat system is practiced extensively in the IGPs. Farmers in this area use irrigation water, which may contain high amounts of K. The estimated addition of K through irrigation in certain areas could be as high as 80-100 kg ha^{-1}. At the same time, the soils in this region are light textured and percolation losses are also very high. So the potential for percolation loss of K, added through irrigation water and released from non-exchangeable K pools of minerals, can also be high. This also suggests that the K balance in intensive rice-wheat systems in the North West India, where the system grain yield can reach as high as 12 t ha^{-1} with an equivalent amount of non-grain biomass, could be highly negative even at the high rate of addition of K through irrigation water, thereby advocating the external addition of K in order to sustain the productivity. Highly variable K content in irrigation water and variability in residue management across the IGP will require very site-specific estimation of such balance in the rice-wheat system. The emerging rice-maize system offers a major challenge to maintain the K balance in the soil. Among the major reasons, the ecosystems where rice- maize systems are thriving (Eastern India, Bangladesh, South India) generally do *not* have high K content in irrigation water and the retention of rice and maize residues in the field is not a common practice for their use elsewhere. Besides, the dry-matter yield of rice-maize system is usually much higher than rice-rice and rice-wheat, causing thereby extraction of large amounts of nutrients from the soil. In the absence of effective residue retention practices, large amount of K is exported out of the field with the harvested product and the residues. This suggests that larger K deficits and higher fertilizer K requirement could be anticipated in rice- maize system (Buresh *et al*. 2010). The authors also reported on similar assessment mechanisms for P balance in their article (Buresh *et al*. 2010).

Approaches for Determination of Fertilizer Rate

Witt and Dobermann (2004) suggested that the expected yield gain from the added nutrient or estimated nutrient balance can be used to determine the fertilizer requirements to achieve a targeted yield. The following section provides an example of fertilizer rate calculations based on yield gain, from nutrient input-output balance (full maintenance) or from a combined yield gain-maintenance approach using K as the target nutrient. In the yield gain approach, the fertilizer K (FK) required to achieve a targeted yield (GY, expressed in t ha^{-1}) is a function of the expected yield gain from the added nutrient, the reciprocal internal efficiency (RIE) for the nutrient, and the use efficiency of the applied nutrient:

$FK = (GY - GY_{OK}) \times RIE_K/RE_K$ .....[4]

Where GY_{OK} is grain yield in t ha^{-1} in the K omission plot, RIE is the reciprocal internal efficiency and RE_K is the recovery efficiency of the applied K, expressed in kg kg^{-1}. Fertilizer K and P requirements to achieve a targeted yield can also be estimated through nutrient input-output balances. Witt and Dobermann (2004) used the following equations based on the nutrient balance to estimate fertilizer K (FK) requirement (in kg ha^{-1}) for a crop with full maintenance of soil K:

$FK = (GY \times RIE_K) + \{(GY - GY_{OK}) \times RIE_K\} - K_{CR} - K_W - K_{OM} + K_L$ ... [5]

Where, K_{CR} is K input with the retained residues, while the other inputs and losses are as defined for equations 1 to 3. Inputs and losses are all expressed in kg ha^{-1}. Witt and Dobermann (2004) included the expected yield gain from the addition of a nutrient ($GY - GY_0$) in the determination of fertilizer requirements to ensure that the fertilizer K rate in the presence of a yield gain were increased by the amount of the nutrient uptake deficit to slowly build-up the native soil nutrient supplies. In the yield gain approach for determining fertilizer K requirement, fertilizer K is only applied when a crop response to the nutrient is certain. A distinctly undesirable feature of the fertilizer K rate determined by the yield gain approach is higher K depletion at high than low target yields. Buresh *et al*. (2010) found that fertilizer K requirement determined by the yield gain approach (Equation 4) increased with increasing target yield; but the K rate did not increase sufficiently fast to prevent increasing depletion of soil fertility with increasing yield within the ranges of the yield gain common for irrigated rice. This could accelerate the onset of nutrient limitations and subsequent declines in productivity in the existing high-yielding areas. At the same time, the full maintenance approach can result in relatively large application of K that may not be profitable at no or low yield gain. Buresh *et al*. (2010) examined two options using nutrient balances to calculate the fertilizer K rates based on partial maintenance with gradual drawdown or depletion of soil K rather than full maintenance of soil K. In one option with partial maintenance, fertilizer K requirement is calculated as a fraction of the full maintenance (FM) as shown in equation 6:

FK with fractional K depletion $= (GY \times RIE_K - K_{CR} - K_W - K_{OM} + K_L) \times FM$ …[6]

The other option with partial maintenance allows depletion of K from soil reserves up to a threshold limit (KS in kg ha^{-1}), which is treated as an input in the nutrient balance:

FK with limited K depletion $= GY \times RIE_K - K_{CR} - K_W - K_{OM} - K_S + K_L$ …[7]

When FM = 1 or when $K_S = 0$, the calculated fertilizer rates for a nutrient ensure full maintenance with no depletion of the nutrient. In the first option (Equation 1), a fraction of the nutrient required for full maintenance of the nutrient input-output balance was allowed to be drawn from the soil nutrient reserve while the rest is applied externally. Buresh *et al*. (2010) showed that this option of partial balance has the risk of higher nutrient depletion and declining productivity at a higher yield target compared to the lower yield targets. Instead, the limited K depletion approach (Equation 7) provides an option of comparable nutrient depletion across yield levels and the nutrient balances are never more negative than the limit for drawdown of soil nutrient reserves (KS), rendering it more attractive than the fractional K depletion approach. Buresh et al. (2010) also combined the partial maintenance and yield gain approaches for determining the fertilizer K rate when crop response to the nutrient is certain:

FK with fractional K depletion $= (GY \times RIE_K - K_{CR} - K_W - K_{OM} + K_L) \times FM) + (GY - GY_{OK}) \times RIE_K/RE_K)$ … [8]

FK with limited K depletion $= (GY \times RIE_K - K_{CR} - K_W - K_{OM} - K_S + K_L) + (GY - GY_{OK}) \times RIE_K/RE_K)$ …[9]

Buresh *et al.* (2010) showed that when the yield gain to applied K is relatively small, fertilizer requirements can be determined with only a partial maintenance approach. When the yield gain is more pronounced, a partial maintenance plus yield gain approach can be considered for determining the fertilizer requirements. In a recent paper, Singh *et al*. (2014a) used the nutrient input-output balance to come up with nutrient recommendations for the targeted yield of rice-wheat cropping system (RWS) in the IGP. The optimum nutrient doses for the RWS in IGP were worked out based on the plant nutrient demand for a targeted yield and nutrient balance calculations. *On-farm* data were used to estimate the reciprocal internal efficiencies (RIE) of rice and wheat (Buresh *et al*. 2010). These values were subsequently combined with the indigenous nutrient supply (INS) and yield gains from the added nutrients to determine the nutrient requirements for rice and wheat for a pre-determined yield target. The components of INS calculations included nutrient (N, P and K) contributions from soil available pool, irrigation water, and rain-fall, and their availability (%, efficiency) to the crop. Thus the nutrient balanace in rice-wheat system is obtained as (Equation 10

$B_{n\ (rw)} = \{(IW_n \times Eff) + (CR_n \times Eff) + (RF_n \times Eff) + (S_n \times \mathbf{Eff)}\}- - \{(GY_r \times RIE_{nr}) + (GY_w \times RIE_{nw})\}$ …(10)

Where Bn is the nutrient balance (N or P or K; kg ha^{-1}), and the IWn, CRn, RFn and Sn are the nutrient (N or P or K) contribution from irrigation water (IW), crop residue, rainfall and soil during the entire rice–wheat cropping cycle, respectively. The term "Eff" is the efficiency (%) of nutrients from different components of INS in terms of their availability to the crops. The GYr and GYw are attainable grain yields (t ha^{-1}) of rice and wheat, respectively, while RIEnr and RIEnw were the reciprocal internal efficiencies for rice and wheat for N or P or K, respectively. The nutrient contributions from IW and RF (kg ha^{-1}) were estimated using total amount of irrigation water applied/ rainfall received (ha-cm) during the rice–wheat cycle, and their N, P and K content. Average available soil N, P and K content (kg ha^{-1}) at the start of the study across the locations was used as contribution from soil. The nutrient input from residues of a crop (CRn) was determined from the amount and nutrient content of the above ground crop biomass retained in the field after harvest and expressed in kg ha^{-1}. The total fertilizer nutrient requirement (kg ha^{-1}) for the RWS {Fn (rw)} was worked out as follows:

Fn (rw) = Bn (rw) $REn(rw)^{-1}$ ..……(11)

Where Fn (rw) is the fertilizer nutrient (N or P or K) requirement for rice (kg ha^{-1}) and REn (rw) is the recovery efficiency (%) of the nutrient N, P and K under rice and wheat crop. Using above equation, Singh *et al*. (2014a) estimated the rates of fertilizer nutrient (N or P or K) requirement for 10 t ha^{-1} hybrid rice and 6 t ha^{-1} wheat grain yields as 300 kg N, 52.3 kg P and 197.6 kg K ha^{-1}, respectively, and applied the same at several locations of the IGP and the neighbouring regions that improved the crop yields, nutrient use efficiency and profitability over the existing practices.

Conclusions

It is thus evident that we shall have to recognize the spatial variability of nutrients among farmers' fields and tailor the recommendations accordingly to improve the productivity, with special reference to areas supporting intensive agricultural productivity of the country in order to render the latter sustainable with minimal environmental footprint., for instance, through nutrient mining which endangers the soil health.

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Saroj Kumar Sanyal,
Ph.D. (Cambridge)

Former Vice-Chancellor, BCKV, Mohanpur, West Bengal, Former Adjunct Professor, Indian Agricultural Research Institute, New Delhi & BAU Sabour Bihar, Former Visiting Scientist, International Rice Research Institute, Philippines

Article 6: Impact of climate change on dynamics of metals and metalloids in soil-plant continuum

Background

Elevated levels of atmospheric CO_2 and temperature have been two important determinants of climate change (Muehe *et al*., 2019). There has been an increase of CO_2 in the atmosphere since, at least, the beginning of the monitoring of atmospheric CO_2 in the 1950s (Frogner-Kockumet *et al*., 2020). International Panel on Climate Change indicated that it is very likely that atmospheric CO_2 concentrations would reach 570 ppmv; compared with the present level, temperature would increase to the tune of 1.5 to 2 °C by the end of this century (IPCC, 2013). However, an update in 2017 projected 5 °C higher temperature and doubled atmospheric CO_2 (about 850 ppmv) over that of present levels (Le Quéré *et al*., 2017). Direct or indirect impacts of climate change have already been evident (Frogner-Kockum, 2020). Climate change has resulted in increase in severity and frequency of extreme weather events such as elevated temperatures, cyclones and heavy rainfall, which may influence mobility and bioavailability of metal(loid)s. A variety of heavy metals are continuously deposited in urban areas from traffic, combustion, various building and road materials, leakage, spills of chemicals, release of untreated waste waters, *etc*. Such metal contaminants are further transported by air, surface runoffs, groundwater flow leading to the contamination of urban waters that influence the drinking water quality and thereby threatens urban health (Chowdhury *et al*., 2016). Ongoing worldwide urbanization process with population growth, migration and the rapidly growing number of mega-cities poses its own challenge in the area of pollution. Implications of all these aspects of metal(loid) pollution need to be understood under changing climatic scenario for developing appropriate mitigation strategy in future. However, systematic research on unraveling the impact of climate change on dynamics of metals and metalloids in soil-plant continuum is at its infancy.

Effect of climate change on yield of crops

It is important to know that how the plant growth and development are affected by climate change in order to understand the effect of climate change on transfer of pollutant elements to plant, i.e. food chains. Reddy *et al.* (2010) attempted to present interactive effects of elevated CO_2 with other environmental variables including temperature, nutrients, water availability and ozone levels in the atmosphere on different plant species (**Table 1**).

Table 1. Interactive influence of elevated CO_2 with different environmental variables among different plant species (Source: Reddy et al. (2010)

Plant species	Treatment	Interacting factors	Response
Gossypium hirsutum	Controlled environmental chamber	Temperature (high)	Positive response
Citrus reticulata	Controlled environmental chamber	Temperature (high)	No response
Betula albosinesis	Controlled environmental chamber	Planting density	Acclimatory response
Betula papyrifera	Controlled environmental chamber	Nitrogen (high)	Positive response
Solanum tuberosum	SPAR chamber	Water stress	Positive response
Quercus mogolica	Controlled environmental chamber	Temperature (high)	Positive response
Hordeum vulgare	Controlled environmental chamber	Dry soil condition	Positive response
Daucus carota	Controlled environmental chamber	High irradiance	Positive response
Molinia caerulea	Controlled environmental chamber	Nutrients (increased)	No response
Betula papyrifera	Controlled environmental chamber	Nutrients (increased)	Positive response
Pinus ponderosa	Open-top chamber	Nitrogen (high)	No response
Brassica napus	Controlled environmental chamber	High temperature drought	Positive response
Gossypium hirsutum	Controlled environmental chamber	Potassium fertilizer	Positive response
Oryza sativa	Controlled environmental chamber	Drought	Positive response
Citrus reticulata	Controlled environmental chamber	Temperature (high)	Positive response
Acacia farnesiana	Controlled environmental chamber	Drought	Positive response
Gleditsia triacanthos			
Leucaena leucocephala			
Parkinsonia aculeate			
Prosopis glandulosa			
Andropogon gerardii	Open-top chamber	Dry season	Positive response
Cucumis sativus	Controlled environmental chamber	Heat stress	Positive response
Larrea tridentate	Controlled environmental chamber	Heat stress	Positive response
Schima superba	Controlled environmental chamber	Temperature (high)	Positive response
Quercus suber	Controlled environmental chamber	Low soil moisture	Positive response
Glycine max	Open-top chamber	Ozone (high)	Positive response
Oryza sativa	Controlled environmental chamber	Ozone	Positive response
Eucalyptus macrorhyncha	Controlled environmental chamber	Low soil moisture	Negative response
Eucalyptus rosii	Controlled environmental chamber	Heat stress	Negative response
Betula populifolia			
Betula alleganiensis			
Acer pennsylvanicum			

The majority of the experiments demonstrate positive response to elevated CO_2 when grown under controlled conditions. The positive response was due to improved photosynthetic rates leading to higher biomass yields. The majority of vegetation belongs to the C_3 photosynthesis group, in which the 'first' product of carboxylation is a 3-carbon acid, phosphoglyceric acid (PGA). Plants belonging to this group operates at less than optimal CO_2 levels and can show dramatic increase in carbon assimilation, growth and yields (Bassham *et al.*, 2003). On the other hand, C_4 plants, in which first the 'first' product of carboxylation is a 4-C acid (e.g. malic acid), the C-4 pathway (Hatch and Slack, 1966), and these plants are considered insensitive to elevated CO_2 atmosphere. Because, photosynthesis in C_4 plants is readily saturated at the normal atmospheric CO_2 concentrations, elevated atmospheric CO_2 and temperature appear to have opposing effects on plant growth and performance (Muehe *et al.*, 2019). Increasing atmospheric CO_2 stimulates the photosynthetic rate and biomass of crops, while increasing temperature above the plant's optimum adversely affect the photosynthetic rate and biomass yields. However, the actual consequences of rise in temperature (above 35°C), associated with increase in atmospheric CO_2 concentration, are yet to be unravelled. One can infer that increase in atmospheric level of CO_2, particularly near plant's optimum temperature, would have positive impact on pollutant element uptake by plants.

Effect of climate change on dynamics of pollutant elements in soil and water

An overview of the impacts of climate change on ecosystems and biota and how this interacts with contaminants is given in **Figure 1**. Although this schematic diagram is indicative, nevertheless, this will help to infer the consequence of climate change on transport and bioavailability of contaminants, which lead to the greater exposure of contaminants to biota.

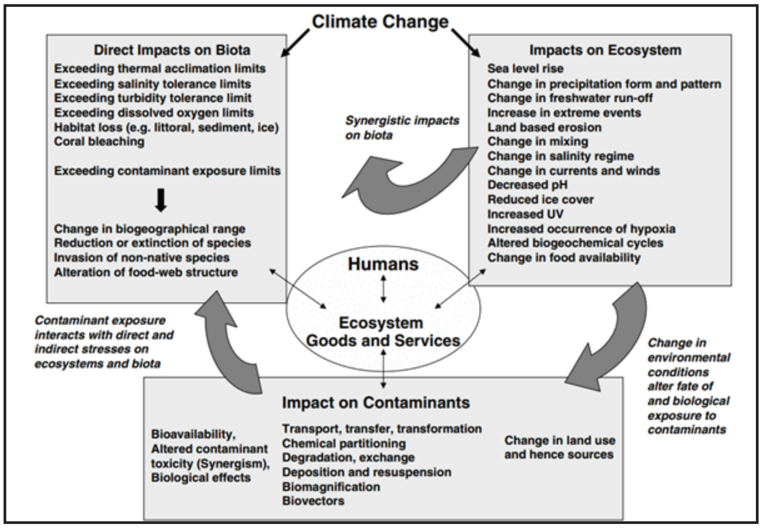

Figure 1. Overview of climate change impacts on ecosystem and biota, and how they interact with contaminants, and their fate and effects (Source: Schiedek*et al.,* 2007)

Major mechanisms by which climate change influences soil processes (related to contaminants) are envisaged as the changes in contaminant exposure and alteration of transport pathways related to changes in precipitation, including surface runoff, precipitation, evaporation, and degradation (Biswas *et al.*, 2018). Besides, climate change may also induce the changes of soil conditions such as soil temperature, soil moisture, pH and redox potential, soil organic carbon, nitrogen and phosphorus, soil minerals etc. Further, climate change may alter contaminant's binding/releasing, oxidation/reduction and speciation of contaminants (**Table 2**).

Table 1 Potential impact of climate change on soil properties/ processes and toxicological aspects of chemical pollutants (Source: Biswas *et al.,* 2018)

Properties and Processes	Potential Impact of Climate Changes	Generalized Toxicological Results
pH	Warming: pH can drop due to formation of sulphate and rhizosphere acidification; pH can raise due to presence of calcite, dolomite or dissolution/weathering of gypsum and aluminosilicates Inundation: pH can raise (if pyrite is formed in the initially during inundation; pH can drop when flood recedes or water level drops due to dissolution of pyrite. Atmospheric deposition: N coupling with acid species increase soil acidity	Soil acidification could increase desorption of heavy metal(loids) from their mineral-bound complex or favor re-mobilization
Temperature	Global warming: Increase of soil temperature; Degradation of SOC increases/more labile fractions to microorganisms; microbial feedback to temperature might be positive	More bioavailability of chemical pollutants; Biodegradation of organic pollutants might increase; Dissolution of metals from its substrate
Soil organic carbon (SOC)	Warming: Degradation of SOC increases/both persistent and labile fractions are vulnerable Erosion: Loss of SOC from soil	More bioavailability of chemical pollutants Mobility of chemical pollutants
Moisture/ rainfall	Water repellence: Growth of microorganism decreases; less vegetation Inundation: Anoxic environment in soil Extreme rainfall pattern: Soil inundation, surface runoff and salt imbalance in soil	Longer residence of pollutants Redox controls the mobility of chemical pollutants; mineral's dissolution can release toxic metals, such arsenic
N and P	Deposition of atmosphere N and load of P from land-use practice: Increase of N and P in soils; acidification of soil	Immobilization of metals (e.g., Cd) in P-supplemented soils; nutrient pollution and surface runoff

Properties and Processes	Potential Impact of Climate Changes	Generalized Toxicological Results
Clay minerals	Erosion: Loss of surface soils Warming: Increase of soil temperature Intensity of light: Light penetration in soil is high	Clay-organic matter disintegration might release heavy metals; loss of clay could reduce microbial function in rhizosphere; partial photodegradation could result in a more toxic metabolite of organic pollutants and thus increased bioavailability of them
Other minerals (e.g., oxides)	Extreme rainfall pattern: Inundation of soils affects redox of soils Temperature: Increase of soil temperature	Redox controls the mobility of chemical pollutants; mineral's dissolution can release toxic metals, such as arsenic
Microor v ganisms, enzyme and plants	Warming: Microbial activity may increase but community structure changes GHG in soil: Community structure changes	Biodegradation of organic pollutants may be increased but the contaminant-specific microbial functions could be affected; plant uptake of metal(loid)s is affected due to climatic influence in rhizosphere

The impact of rising temperature, as a direct consequence of climate change, in turn increased the rate of chemical weathering (due to high temperature and lower pH) leading to the release of metals in the earth crust and soils (Schiedek *et al.* (2007). Environmental redox processes play key roles in the formation and dissolution of mineral phases. Redox cycling of naturally occurring trace elements and their host minerals often control the release or sequestration of inorganic contaminants (Borch *et al*., 2010). Redox processes control the chemical speciation, bioavailability, toxicity, and mobility of many major and trace elements including Fe, Mn, C, P, N, S, Cr, Cu, Co, As, Sb, Se, Hg, Tc, and U. Redox-active humic substances and mineral surfaces can catalyze redox-transformation and degradation of organic contaminants. Increased precipitation or flooding is expected to lead to a potential change in soil redox conditions. Intensification of the hydrologic regime will likely have important impacts on biogeochemical processes and contaminant behavior, but quantifying these impacts experimentally remains a key challenge.

Jarsjö *et al*. (2020) investigated changes in metal(loid) (As and Pb) mobilization in response to possible (climate-driven) future shifts in groundwater level and fluctuation amplitudes under modelling frame work. The results showed that relatively modest increases (0.2 m) in average levels of shallow groundwater systems, which may occur in Northern Europe within the coming two decades, can increase mass flows of metals through groundwater by a factor of 2 -10. There is a similar risk of increased metal mobilization in regions subject to increased (seasonal or event-scale) amplitude of groundwater level fluctuations. Climate change implications on pollutant element dynamics in aquatic system was studied by Hauser-Davis and Wosnick (2022). These authors made projections that metals being non-degradable, would comprise a significant concern for aquatic ecosystems, more so under changing climatic scenario (T**able 3**).

Table 3. Effect of climate change contamination of water body (Source: Hauser-Davis and Wosnick, 2022)

Type of Water Body	Expected Climate Change Effects
Freshwater systems	Groundwater variations, directly affecting groundwater contamination;
	High groundwater levels, resulting in topsoil contaminant removal;
	More frequent river discharges, resulting in differential freshwater metal and metalloid inputs.
Estuaries and mangroves	Increased erosion processes due to sea level rises, resulting in the dissociation of deposited sulfides;
	Saline mangrove intrusion oxidizing deeper sediment layers, releasing metals and metalloids and increasing their bioavailability to local biota;
	Altered annual rainfall rates altering material flows.
Marine environment	Altered ocean currents leading to changes in metal transport;
	Changes in the sediment-water interface due to alterations in metal speciation, solubility, and concentration gradients, as well as oxidation-reduction interface potentials;
	Increased rainfall periods resulting in pulses of high trace metal fluxes to the ocean;
	Ocean acidification resulting in increasing metal and metalloid bioavailability.

Precipitation has a direct impact on surface runoff, river discharge, and thus indirectly on the river water quality. A good correlation between a short-term increase in precipitation and increase in suspended sediment concentration and as well as an increase in metal contaminant transport in rivers of Gothenburg, Sweden was noted (Frogner-Kockum*et al*., 2020). Surface runoff is an important carrier of contaminants from the surrounding land to the receiving surface water body. The linkage between surface water quality and precipitation seems to be more evident during heavy rainfall (Rostami *et al*., 2018). Urban groundwater quality is affected by infiltration of storm-water, wastewater leakage, and spills as well as leakages from point sources (Frogner-Kockum*et al.* 2020).

There is an extreme scarcity of concrete experimental evidences, which relate and quantify the impact of climate change on dynamics of pollutant elements in soil. In a classical greenhouse study, it was shown that climate change may cause a greater proportion of pore-water arsenite, the more toxic form of arsenic (As), in the rhizosphere of Californian Oryza sativa L. (**Figure 2**; Muehe *et al*. 2019). Increasing temperature further exacerbates the partitioning of As from solids to pore-water, stimulating the reductive dissolution of As-bearing Fe (III) (hydr)oxides with the concomitant increase in pore-water arsenite and iron concentrations. Increasing atmospheric CO_2 concentrations also stimulated microbial respiration in the rhizosphere (increased inorganic pore-water carbon) causing reductive dissolution of Fe(III) (hydr)oxides and As oxidation. An increase in temperature and/or atmospheric CO_2 led to increases in organic carbon exudation from plants and microbes (shown by increased organic carbon in pore-water) and increases in microbial activity as noted by the dissolved inorganic carbon (DIC) levels, and thus, greater oxygen demand and greater As(V)/Fe(III) reduction with increases in temperature.

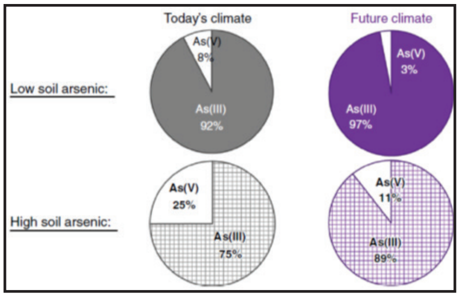

Figure 2. Proportion of dissolved arsenic [Pore-water arsenite (As(III)) and arsenate (As(V)] contributions under different climatic and soil arsenic conditions during grain filling stage of rice; low soil arsenic: 7.3 mg/kg and high soil arsenic: 24.5 mg/kg; today's climate (33 °C temperature and 415 ppmv CO_2 and future climate (38 °C temperature and 850 ppmv CO_2): (Source:Mueheet *al.*, 2019).

Effect of climate change on plant uptake of pollutant elements

By and large, under simulated climate change in terms of elevated CO_2 and temperature was reported to have positive impact on accumulation of metals in some of the important crops grown in polluted soils (**Table 4**). However, effects of climate change on plant growth in metal polluted soils will be complex, particularly plant species with narrow ranges of tolerance to various stress factors may have difficulty adapting to future climatic conditions (Rajkumar *et al.*, 2013). Direct and/or indirect effects of climate change on enhanced heavy metal mobility in soils may further hinder the ability of plants to adapt and make them more susceptible.

Table 4. Effects of various environmental parameters on the plant growth and the uptake of metals by plants grown in polluted soils (Source: Rajkumar *et al.*, 2013)

Climatic factors and heavy metals	Agent	Plants	Effects of altered climatic condition and pollutants on plant growth and metal uptake
Cd and Cu	Elevated CO_2	Rice and wheat	Elevated CO_2 levels lowered the pH of the soil through increasing root exudation and thereby improve Cu and Cd mobilization
Cu, Zn and Fe	Elevated temperature	Potato	Increased Cu, Zn and Fe concentrations in leaves, but decreased Cd, Pb, Fe, Zn and Cu concentrations in tubers
Cd	Elevated temperature	Wheat	Cd toxicity increased in parallel with temperature
		Wheat	Higher temperature reduced root elongation through enhancing Cd accumulation in roots and affecting subcellular distribution of Cd.

Under controlled conditions, Muehe *et al.* (2019) reported that a shift to future climatic conditions (38 °C, 850 ppmv CO_2) from the ambient ones alone resulted in a 16% yield loss, while increased total soil As alone caused a yield loss of almost 40%. The combined impacts of changing climatic conditions and increased soil arsenic resulted in a 42% decrease in yield. Similarly, dehusked rice grain grown on low As soil contained a total of 393 ± 16.9 µg As kg^{-1} grain, of which 250 µg As kg^{-1} grain was inorganic arsenite under ambient conditions This was increased to 580 ± 21.0 µg As kg^{-1} with the contribution of inorganic arsenic doubling in the grain to 450 µg As kg^{-1} under elevated climatic condition. With increased total soil As alone, the total amount of arsenic in the grain increased to 821 ± 30.4 µg As kg^{-1} grain with the contribution of inorganic arsenic remaining at 250 µg As kg^{-1} grain. The combined impacts of changing climatic conditions and increased soil As resulted in a total grain arsenic increase to 1004 ± 17.9 µg As kg^{-1} grain with 400 µg As kg^{-1} being inorganic arsenic (Muehe et al. 2019).

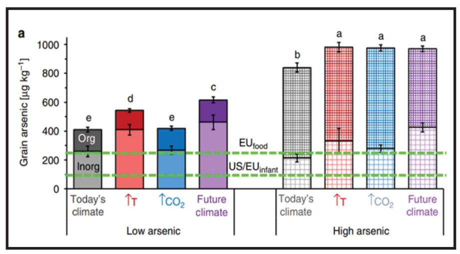

Figure 3. Arsenic contents in *Oryza sativa* L. grains produced under different climatic and soil arsenic conditions. Low soil arsenic: 7.3 mg/kg and high soil arsenic: 24.5 mg/kg; today's climate (33°C temperature and 415 ppmv CO_2 and future climate (38°C temperature and 850 ppmv CO_2): (Source: Mueheet *al.*, 2019).

Conclusions

There is an urgent need of conducting the experiments under simulated conditions for assessing impact of climate change, particularly elevated levels of CO_2 and temperature, on metal(loid) solubilization and mobility *vis-a-vis* their transfer to plants. Wide knowledge gaps exist in the area, which need to be bridged for formulating actionable evidence-based hypotheses and predictions about the wider implications of climate change for plant–metal interactions across agricultural, non-agricultural and aqueous systems.

S.P.Datta,
Director
IISS Bhopal

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Research Papers

1 Harisadhan Malakar, Gagan Timsina, Jintu Dutta, Arup Borgohain, Diganta Deka, Azariah Babu, Ranjit Kumar Paul, Md. Yeasin, **Feroze H. Rahman**, Saumik Panja and **Tanmoy Karak** (2022). Sick or rich: Assessing the selected soil properties and fertility status across the tea growing region of Dooars, West Bengal, India. *Frontiers in Plant Science.* **Vol 13**, pp:1-22. DOI 10.3389/fpls.2022.1017145. December 2022 (NAAS 12.63)

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Contact:

Dr. Gouranga Kar, President,
Mobile: 9438362587, E-Mail: director.crijaf@icar.gov.in

Dr. F. H. Rahman, Secretary
Mobile: 9432955117, 8240233329, E-Mail: secretaryissskol@gmail.com

ICAR- National Bureau of Soil Survey and Land Use Planning
Block- DK, Sector – II, Salt Lake, Kolkata – 700091, West Bengal, India
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