National Seminar on

Recent Developments in Nutrient Management Strategies for Sustainable Agriculture: The Indian Context

18-19 June, 2022

Souvenir

Organized by

Department of Soil Science & Agricultural Chemistry

Bihar Agricultural University, Sabour

In collaboration with

Indian Society of Soil Science, Sabour Chapter

National Seminar on

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Title: Souvenir, National Seminar on *“Recent Developments in*
Nutrient Management Strategies for Sustainable Agriculture: The Indian Context

June, 2022

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Published by : Bihar Agricultural University, Sabour, Bhagalpur-813210
University website: www.bausabour.ac.in

Cover Designed by : Mr. Brajesh Kumar Tiwari, Media Centre, BAU, Sabour

ISBN. : 9789394490932

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31 मई 2022

संदेश

मुझे यह जानकर प्रसन्नता हो रही है कि बिहार कृषि विश्वविद्यालय, सबौर में 18 एवं 19 जून, 2022 को ‘‘भारतीय संदर्भ में टिकाऊ कृषि हेतु पोषक तत्व प्रबंधन को रणनीतियों का अद्यतन विकास विषय पर एक राष्ट्रीय संगोष्ठी का आयोजन किया जा रहा है।

खाद्य उत्पादन बढ़ाने के लिए गहन कृषि ने पोषक तत्वों के असंतुलन की समस्या पैदा कर दी है। इसके फलस्वरूप मिट्टी में पौधों के लिए आवश्यक पोषक तत्वों का क्षरण हो रहा है और मिट्टी की उर्वरता में भी कमी आई है। इस समस्या से निपटने एवं मिट्टी के पोषक तत्वों के संरक्षण हेतु इनका प्रबंधन अत्यंत महत्वपूर्ण है।

मुझे आशा है कि कृषि वैज्ञानिकों, विशेषज्ञों और छात्रों के साथ चर्चा और विचार–विमर्श से इस संगोष्ठी में भाग लेने वाले सभी हितधारकों को प्रभावी रणनीतियों की पहचान करने में मदद मिलेगी और टिकाऊ कृषि से मिट्टी में पोषक तत्वों का उचित प्रबंधन हो सकेगा। आशा है, इन प्रयासों से उत्पादन एवं उत्पादकता सुधार होगा। में वृद्धि होगी और किसानों की आर्थिक स्थिति में भी सुधार होगा।

मैं आयोजकों और इस संगोष्ठी में भाग ले रहे प्रतिभागियों को हार्दिक बधाई देता हूँ।

(फागू चौहान)

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नरेन्द्र सिंह तोमर
NARENDRA SINGH TOMAR

कृषि एवं किसान कल्याण मंत्री
भारत सरकार
कृषि भवन, नई दिल्ली
MINISTER OF AGRICULTURE & FARMERS WELFARE
GOVERNMENT OF INDIA
KRISHI BHAWAN, NEW DELHI

Message

I am pleased to hear that the Department of Soil Science and Agricultural Chemistry, Bihar Agricultural University, Sabour in collaboration with the Indian Society of Soil Science, Sabour chapter is organizing a National Seminar on "Recent Development in Nutrient Management Strategies for Sustainable Agriculture: The Indian Context" at Sabour, Bhagalpur, Bihar during June 18-19, 2022.

Intensive cropping tends to deplete the available contents of plant nutrients due to which efficient soil fertility management in the intensively cultivated parts of the country becomes indispensable for maintaining the crop production. Soil nutrients lost from the soils or removed by crops from an agricultural field usually exceeds the amount replenished to the field. Mining of essential plant nutrients leads to a decline in the soil. fertility and is a serious threat to food security of the country. This makes it extremely necessary to formulate and disseminate effective nutrient management strategies among end users i.e. farmers and other agricultural beneficiaries.

I hope this seminar will definitely help in arriving at meaningful conclusions from the discussions among agricultural scientists, students and progressive farmers regarding optimum use of fertilizers and soil health management.

I wish the Organizing team of the National Seminar a grand success.

(Narendra Singh Tomar)

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Minister of State, Housing & Urban Affairs
Government of India

D.O.MOS/H&UA/VIP/2022/354

Message

I am happy to learn that Bihar Agricultural University, Sabour organizing a national seminar on "Recent Developments in nutrient management strategies for sustainable agriculture: The Indian Context" during June 18-19, 2022 at Sabour, Bhagalpur, Bihar.

Since the Green Revolution era, the farming sector exploited the soils for food, fiber, fodder, etc., with high input responsive varieties that excavated vast amounts of chemical fertilizers. The burgeoning population of the country calls for a commensurate increase in food production to satisfy the demands of its inhabitants. Due to innovative mechanization in agriculture, specialization, and government policy programs, the productivity of food has soared. Regrettably, intensive agricultural operations degraded the soil quality. India has lost 68% innate productive capacity of agricultural soils. This plunder of land's quality continues unabated, further resulting in low nutrient use efficiency and insufficient yields of agro-ecosystems. Therefore, this is high time to realize the dreadful impacts of intensive crop production on the natural ecosystem. Irrefutably, both soil and its nutrients are the wondrous gifts of nature to humankind; utilizing them sustainably is imperative. The present seminar will highlights the impacts of non-judicious nutrient management on soil productivity, nutrient use efficiency, and novel technologies required to promote sustainable agriculture and achieve the target of doubling farmer's income in India.

On this occasion, I congratulate the organizers for organizing national seminar on topic of relevance in a timely manner.

(Kaushal Kishore)

New Delhi.
Dated: 15.06.2022

Room No. 130-C, Nirman Bhawan, New Delhi-110011, Ph.: 011-23061999, 23063071, 23061103

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दिनांक 15.06.2022

संदेश

मुझे यह जानकर प्रसन्नता हो रही है कि बिहार कृषि विश्वविद्यालय, सबौर, भागलपुर बिहार में सतत कृषि के लिए पोषक तत्व प्रबंधन रणनीतियों में हालिया विकास भारतीय संदर्भ पर दो दिवसीय राष्ट्रीय संगोष्ठी का आयोजन कर रहा है। सबसे महत्वपूर्ण पोषक तत्वों पर ध्यान केंद्रित करने से कुछ मामलों में पोषक तत्वों में असंतुलन पैदा हो गया है जिसके परिणामस्वरूप वायु और पानी की गुणवत्ता, जैव विविधता और मानव स्वास्थ्य पर प्रभाव के साथ पर्यावरण को भारी नुकसान हुआ है। सभी पोषक तत्वों के बेहतर प्रबंधन की आवश्यकता है जो टिकाऊ कृषि प्रदान करता है और अपशिष्ट, आर्थिक नुकसान और पर्यावरणीय प्रभावों को कम करते हुए खाद्य उत्पादन में आवश्यक वृद्धि को बनाए रखता है। अधिक व्यापक उत्पादन प्रणालियों टिकाऊ साबित हो सकती है। खेतों पर पोषक तत्व प्रबंधन भूमि प्रबंधक के नियंत्रण में है और उन्हें उत्पादन लक्ष्यों को प्राप्त करने के लिए अच्छी प्रथाओं के अनुरूप होना चाहिए जो अनिवार्य रूप से टिकाऊ कृषि के सभी वांछित लक्ष्यों को कवर करते हैं।

मैं इस अवसर पर संस्थान के अकादमिक और प्रशासनिक कर्मचारियों को शानदार प्रयास के लिए बधाई देती हूँ और भविष्य के सभी प्रयासों के लिए आयोजकों को शुभकामनाएँ देती हूँ।

रेणु देवी
15.6.22

(रेणु देवी)

Amrendra Pratap Singh
MINISTER
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Govt. of Bihar

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Ref. : 229

Date : 30.05.2022

Message

I am delighted to hear that Bihar Agricultural University is organising a National Seminar on "Recent Developments in Nutrient Management Strategies for Sustainable Agriculture: The Indian Context" on 18 and 19th June, 2022 at Sabour, Bhagalpur, Bihar.

It is well established that fertiliser use has radically changed the crop output since the green revolution era in India. The momentum, however, slowed in the past decade. Imbalanced fertiliser application in crops is identified as one of the major reasons for decreasing crop response to fertiliser application and the consequent lower crop production growth rate in the country. The lack of appropriate tools and implementation mechanism has been a major hindrance that restricted wide scale adoption of recent nutrient management strategies by our farmers. Addressing the use of newer nutrient management techniques for sustainable agriculture has raised concerns about their feasibility as well as their environmental sustainability.

I am sure that eminent experts present in the seminar will certainly come with fruitful strategies for sustaining our agriculture *vis-a-vis* maintaining the quality of our soils. I express my best wishes to the organizers and participants of the seminar and further extend my happiness and greetings for the success of the seminar.

(Amrendra Pratap Singh)

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डॉ. सुरेश कुमार चौधरी
उप महानिदेशक (प्राकृतिक संसधान प्रबंधन)
Dr. Suresh Kumar Chaudhari
Deputy Director General (Natural Resources Management)

19.05.2022

Message

Soil is referred to as Mother in our country. Caring soil is extremely important for sustaining healthy life on earth. Deterioration of soil health is considered as one of the main reasons of declining / stagnation of agricultural productivity in the country. It is our prime duty to save the soil to meet out the future demands of food for an ever increasing population. Major management options include soil test based balanced and integrated nutrient management, improving nutrient use efficiency, bio engineering measures of soil & water conservation, crop residue recycling. soil reclamation / amelioration measures, conservation agricultural practices, capacity building through training and demonstration to educate farmers and field functionaries.

I am pleased to learn that the Bihar Agricultural University in collaboration with the Indian Society of Soil Science, Sabour chapter is organising a National level Seminar on '*Recent Developments in Nutrient Management Strategies for Sustainable Agriculture:* The Indian Context during 18-19 June, 2022 at Sabour, Bhagalpur. I am sure that eminent experts present in the workshop will certainly come out with fruitful recommendations for nutrient management in a sustainable manner that is applicable at the field level.

I express my best wishes to the organizers and participants of the seminar.

(S.K. Chaudhari)

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No.__________/Dr RPCAU (VC)

Date : 21.05.2022

Message

I am pleased to know that the Bihar Agricultural University in collaboration with the Indian Society of Soil Science, Sabour Chapter is organizing a National Seminar on Recent Developments in Nutrient Management Strategies for Sustainable Agriculture: The Indian Context during 18-19 June, 2022 at Sabour, Bhagalpur.

A sustainable nutrient management strategy within the soil must ensure high and sustainable food grain production, high net profit, build-up of native available soil nutrients and avoidance of over fertilization. Although, the combination of organic fertilizers with inorganics considered a stock of nutrients which can continuously supply the current crop with their requirements, it can also be considered as a scheme which has greater residual effect on subsequent crops than sole application of inorganic fertilizers, due to slow release of nutrients over time and its added value in soil organic matter content. Farmers and researchers cannot neglect the role of the soil microorganisms in controlling nutrient conversions, solubility, availability, release from the soil root zone to plant roots and also the role in absorption and raising nutrient-use efficiency, which can be achieved by following the INM system.

I feel this seminar will sensitize the participants and discussion among the expertise will help in developing effective strategies for better implementation of management practices for future research and development.

I extend my happiness and greetings for the success of the seminar.

RSrivastava

(R. C. Srivastava)

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Date : 18.05.2022

Message

It is a matter of immense pleasure that the Department of Soil Science and Agricultural Chemistry, Bihar Agricultural University, Sabour in collaboration with the Indian Society of Soil Science, Sabour chapter has taken up the initiative to organize a two-day National Seminar on "Recent Developments in Nutrient Management Strategies for Sustainable Agriculture: The Indian Context" at Sabour, Bhagalpur, Bihar during June 18-19, 2022.

General agricultural practices are considerably less effective in maintaining or enhancing the soil fertility and productivity. A short-term increase in crop yields may be more likely. attributed to use of high yielding crop varieties under the influence of high use of chemical fertilizers and better irrigation management. An increasing yield also means more nutrients are removed from soil, and if proper nutrient management practices are not followed judiciously, we may see a decrement in crop production in the near future owing to nutrient inadequacy. Even though alternative supplementary methods for nutrient management, like crop residue incorporation, composting, green manuring and biofertilizer technologies have been recommended for soil improvement for a very long time, only a small portion of the farmers adopt the techniques in a proper manner. Integrated technologies for nutrient management in crop production is indispensable for sustainable agriculture, and an elaborate scientific discussion among scientists, students and other individuals involved in the field of agriculture will help identify pertinent issues related to formulation and implementation of holistic nutrient management modules for enhanced crop production simultaneously sustaining the soil health.

I congratulate the academic and technical staff of this University for the praiseworthy effort and extend my best wishes to the organizing team for all future endeavours.

18-05-22

(Arun Kumar)

Application and validity of various nutrient management approaches in the Indian context

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Nutrient management for raising crop plants has been the focus of humans very since the advent of civilization. Even before the humanity was introduced to the realm of essential plant nutrients, there was a realization of the *elements* in crop nutrition, which included tillage, rain and sunshine. To start with, this concept was perfectly logical from the standpoint of the then level of knowledge in the human domain. However, the then considered *elements* later came to be recognized as factors in crop production and continue to be so till date. While considering various approaches for nutrient management and their relevance in the present context, these factors do have a strong bearing on the availability of various plant nutrients. In this composition, we first consider the classical physical, chemical and biological considerations for plant nutrient management and explore their applicability and validity under Indian conditions. The discussion then goes to the prevailing practices for crop nutrient recommendation and management, again in the Indian context. The discussion is then summarized to draw some conclusions about the application and validity of various nutrient management strategies in the Indian context.

Soil physical considerations vis-à-vis availability of essential plant nutrients roam around (i) the availability of water for ensuring nutrient supply, (ii) maintenance of optimum soil physical environment for root growth and penetration as well as movement of air and water in the soil and, finally, (iii) the net outcome of long-term soil formation processes and the soil degradation processes such as erosion. Soil physical constraints that limit crop productivity by way of stressed water availability are more pronounced in the less favoured areas such as the rainfed areas. The rainfed ecologies are inherently multifaceted, diverse, delicate, risky, usually overlooked, neglected and call upon site specific management strategies. Soil and water are the most critical resources for attempting an inclusive development strategy, keeping in mind the tremendous temporal and spatial variability in the amount and distribution of rainfall. All these constraints get magnified under the effect of climatic changes that are becoming a glaring reality. Hence the approaches for soil conservation, rainwater harvesting and management, micro-irrigation, conjunctive use of available water resources and various agro-techniques for overall soil health management find relevance in maintenance of optimum soil physical conditions for ensuring an efficient nutrient management scenario. The soil profile penetration resistance has a direct relation with the resistance the roots are likely to encounter while growing through the profile. This profile penetration resistance thus affects the availability of nutrients for the crops from various depths in the profile, so also the release of root exudates and availability of detritus for microbial activity at various depths in the root zone. Moreover, the soil profile penetration resistance is influenced by management interventions such as cropping systems, fertilizer and manure application practices and irrigation besides those factors that might directly affect the profile penetration resistance such as sub-soiling or deep tillage. Similarly, primary and secondary tillage operations tend to make the soil environment more congenial for the growth of targeted crops by helping a good stand development as well as minimizing the competition from associated weeds and other pests. Soil conservation measures, be it agronomic or installation of engineering structures, aim to retain the fertile top soil for plant growth. Such practices have immense benefits as evident in areas where soil conservation measures have raised the productivity of corps over that of the neighboring areas where no conservation measures have been followed. Another very relevant application of soil physical consideration is through improved residue management and recycling practices. Crop residues, upon decomposition recycle the nutrient elements to the soil, but at the same time add organic matter for overall improvement of the soil physical environment, which has a indirect bearing on root growth, water relations and nutrient transformations and dynamics in the soil system. Although, such a concept does not directly seem to be influencing nutrient availability and its effects are also observable only over the long term, the maintenance of *soil physical fertility,* i.e., the management leading to creation of an enabling soil environment for soil to perform its designated functions is truly relevant under Indian conditions.

Soil chemical considerations, as obvious, include (i) the available pools of essential soil nutrients and their transformations to and from sparingly available and unavailable pools, (ii) soil pH and the competition from other nutrients, and (iii) inputs and outputs of nutrients on a system basis. Given a set of soil physical conditions, such considerations have a direct bearing on availability of nutrients for various crops. These considerations are of a more obvious nature considering that the nutrient management practices have a direct bearing on these considerations. Say for instance, fertilizer application practices, irrigation and drainage are deemed to be influencing not only the nutrient availability in soils but also the transformations of these nutrients and movement to and from organic and mineral forms of these nutrients. Application of selective nutrients affects not only the availability of that particular nutrient but also the availability of various other nutrients that might have either a synergistic or antagonistic relationship with that nutrient. Soil reaction influences the direction of various nutrient transformation reactions in the soil. At the same time, addition of various sources of the nutrients to a soil has a bearing on soil reaction. Besides this, the extremes of soil reaction encountered in the soil system such as the acidic soils to the alkali soils, all have their typical characteristic nutrient availability related constraints. The extremes of soil reaction conditions have diverse recommendations from a management point of view. Further, given the prevalence of such recommendations, soil pH is a major factor in selecting the management intervention. The nutrient recommendations in a site specific approach not only to take into consideration the inherent soil chemical characteristics and fertility evaluation, but also account for the historic management that has led the soil to its current state. For instance, a site specific approach for nutrient recommendation could also account for the historic crop rotations being followed, residue management options being exercised and the fertilizer and manure application behavior of the cultivator, besides taking into account the historic yield levels for various crops of the system. Thus site specificity is of great relevance in deriving the balance of nutrient inputs and outputs and then making nutrient recommendations.

Soil biological considerations involve largely the biological nutrient transformations within the soil as well as in continuity with the soil environment. These considerations also consider the cycling of organic matter from plant detritus as well as inputs and removals by the macro-organisms and anthropogenic activities. Now given a set of prevailing soil physical conditions and fertility encompassing the physico-chemical characteristics of the soil, the soil organisms, both micro and macro, make the soil lively and dynamic. It is important to emphasize at this juncture that rather than the net amount of nutrients available for plant uptake at any point of time, the gross quantity of nutrients being cycled from one trophic level to other is of greater significance from an ecological standpoint in plant nutrition. The importance of nutrient cycling is emphasized not only within the soil but also beyond the realm of the physical soil – from the crop canopies to the aerial and aquatic environments in the vicinity. These cycling processes and the interactions between various trophic levels make the soil stand apart from the weathered unconsolidated material found at the surface of extraterrestrial bodies. Such an approach that considers the requirement of organisms at various trophic levels has been a part of the traditional Indian farming practices in vogue throughout the country. Say for instance, in modern agricultural science, there is an emphasis on diversification of the system; which is already deep rooted in the traditional Indian farms where the trees, shrubs and under-storey plants can be seen growing harmoniously with organisms within and on the soil; not only in practice, but with a deep conviction that this is the way it should be.

As per the ground situation, there are certain practices that have been adopted by the farmers for ages, some have found only a relatively lower acceptance and some are still in the stage of demonstrations but far from adoption. Soil and water conservation practices such as summer plowing before the onset of rains, mulching and use of crop residues, intercropping, manuring, agroforestry, traditional crop establishment such as relay cropping are various types of resource conservation technologies that have found a wider acceptance among the Indian farmers. However, with the availability of cheap sources of irrigation, conservation practices take a back seat and there is a neglect of the RCTs. The need is to emphasize the adoption of RCTs, which have the potential to sustainably enhance the input use efficiencies. The application of chemical fertilizers has found a large scale adoption in most parts of the country. But purchasing power and timely availability of chemical fertilizers is still a constraint. Besides this, the application of chemical fertilizers is quite often done based on peer pressure and past experiences without any scientific recommendation. The adoption of state advocated general fertilizer recommendations is quite low. Soil testing has been emphasized on a magnanimous scale but has still not delivered the desired benefits. Other criteria for site specific nutrient management such as various App based nutrient recommendation methods have been a slow starter. However, there is sufficient scientific evidence to support adoption of SSNM on a large scale and these technologies are quite relevant. Precision nitrogen management is also being emphasized. Though the hand held tools such as SPAD meter and GreenSeeker are interestingly promising, they still need to be customized as an adoptable package under the Indian conditions. At the same time, low cost precision nitrogen management tools such as Leaf Colour Chart have been adopted successfully, though in certain pockets only, suggesting their relevance in the Indian context. The use of microbial consortia for a plethora of purposes including residue decomposition, nitrogen fixation, phosphorus solublisation and potassium mobilization is advocated and adopted at a significant scale. But this needs far greater emphasis, both in terms of farmer level adoption as well as visible improvement in quality of the technologies per se.

The way forward is undoubtedly to press for greater adoption of the above discussed and other physical, chemical and biological approaches for nutrient management in an integrated manner. An integrated approach with concerted efforts towards adoption of resource conservation technologies, site specific nutrient management including app based nutrient management and soil testing should be emphasized for curtailing nutrient mining and balanced plant nutrition. The biofertilizer technologies are also seen as cost effective relevant tools to support agricultural development in an eco-friendly manner. Besides working for adoption of the existing technologies and nutrient management strategies, need based and site specific adaptation of technologies needs to be prioritized for refining and improving the strategies in a holistic manner.

Nutrient Management Strategies for Sustainable Intensification of Agriculture

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Supply of essential nutrients through fertilizers has played a vital role in increasing food production and ensuring food security to billions across the globe. It has been estimated that the fertilizer application contributed to the extent of almost 40 percent in enhancing the production and productivity of food crops in India a major pillar of green revolution. The compulsion to produce more for the global human population expected to touch 10 billion by 2025 inevitably implies more application of fertilizers. However, their injudicious, indiscriminate and unbalanced use has led to degradation of natural resources, particularly soil and water, and an adverse impact on the environment. One very adverse impact has been the increase in nitrous oxide emissions, which has a Global Warming Potential (GWP) almost three hundred times that of carbon di oxide. It has been estimated that the nitrous oxide emission increased almost four times during the period 1970-2010. In fact, the contribution of methane presently to GHGs concentrations is less than the nitrous oxide in Indian Agriculture.

India’s rank is second both in production and consumption of nitrogen (N) and phosphatic (P_2O_5) fertilizers after China. India imports all its potassic (K_2O) fertilizer requirement but is ranked fourth after China, Brazil and USA in its consumption. With the intensive mining of nutrients associated with high productivity levels that has taken place over decades, deficiency of nutrients in Indian soils is on the increase and it is not only confined to the major nutrients but also has led to deficiency of secondary (Sulphur) and a host of micro-nutrients (Zinc, Boron, Ironetc).It is well established that micro-nutrients play a vital role in enhancing productivity and quality of crops and are also required for prevention of many health-related issues in animals and human beings. “One Health” is now being talked about globally which highlights the importance of soil-plant-animal-human-environment health as one system. To continue increasing agricultural production to meet the diverse demands of the population, intensification of agricultural-related activities in a sustainable manner is the only option. This becomes all the more important considering India’s commitment to the Sustainable Development Goals (SDGs) to be achieved by 2030.

The Govt. of India spends a considerable amount of money in the form of subsidy to fertilizers to make them available to the farmers at an affordable cost. The Govt. of India has allocated more than Rs. Two Lakh Crores as subsidy for the year 2022-23 in view of the escalation of fertilizers costs in the international market. However, the availability of the fertilizers at low cost does not encourage efficiency and the nutrientuse efficiencies are very low being 30-50% for nitrogen, 15-20%

of phosphorous and 70-80% for potassium. In case of sulphur it is less than 10% and in micronutrients it is less than 5%.

Obliviously, there is a lot of scope for improving the nutrient use efficiencies which can be easily increased by a minimum of 10% by adopting measures like split application, furrow placement, use of urea super granules, band placement etc. The Govt. of India's decision to make only neem coated urea available in the country has definitely increased its use efficiency. In spite of the so many alternatives available, broadcasting of fertilizers is still the most common practice followed by farmers. It is a well-known fact that any technique that improves water use efficiency also leads to increase in nutrient use efficiency. Laser levelling is one very typical example. Drip fertigation system can enhance the nitrogen use efficiency by more than ninety percent. Phosphorus use efficiency can be enhanced upto forty five percent. All these measures contribute to reduction in the GHGs emissions. Nano products also have the potential of enhancing the nutrient use efficiency. India is the first country in the world to develop Nano urea which is now being used on a large scale particularly through drones. Nano DAP is likely to be available very soon. However, there is scope of including micro-nutrient application in fertigation systems in particular. A very long-standing recommendation has been to substitute twenty five percent of the chemical fertilizers by organic sources including bio fertilizers in view of their beneficial effects on soil health. An overall reduction in the use of chemical fertilizers by 25 percent at the national level would definitely reduce the subsidy burden, improve soil health and enhance eco-system services. It is also time to explore other sources of nutrients. Crop residues are now being produced in large quantities. They are a good source of nitrogen, phosphorus, potash and sulphur as well as organic carbon. Bio-char use also enhances fertilizer use efficiency. Wastewaters being generated in cities is another source of nutrients after removal of heavy metal contaminants. It is also time to shift to precision farming to enhance both production and productivity and enhance nutrient use efficiency.

Nutrient Management Strategies for Enhancing Use Efficiency and Crop Growth in Salt Affected Soils

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Introduction

Salt affected lands are estimated at about 955million ha worldwide (FAO, 2008), afflicting over 6% of the world's total arable land (Flower *et al*., 1997) of which sodic soils constitute 581million ha. The Indo-Gangetic Plains in India has about 2.7 million ha of salt affected lands, consisting mostly of centuries-old barren sodic soils with no land use opportunities (NRSA and Associates, 1996; Singh *et al*., 2010). These soils have high pH (>8.5), exchangeable sodium percentage (ESP) >15 and the presence of soluble carbonate and bicarbonate that produce alkaline hydrolysis products such as Na_2CO_3 and $NaHCO_3$ adversely affect the soil physicochemical and biological properties resulting significant reduction in yields of most crops. Population growth is the major concern to increase the production and productivity of crops. It is expected that the world population by the end of 2025 will be about 8 billion and 9.3 billion by 2050 (US Census bureau 1998). The crop productivity is not increasing to a similar proportion as world population. Because of urbanization and water scarcity, the expansion of land use for food production has almost stagnated and showing a downward trend for many important crops with high input requirements.

Salt-affected soils

Efficient, balanced and integrated nutrient management is an integral part of reclamation of sodic lands. It has been demonstrated that highly deteriorated sodic soils can be reclaimed by using gypsum @ 25% GR+FYM@20 Mg ha^{-1} and long-term productivity of rice and wheat and soil fertility could be sustained. Plants grown in alkali soils suffer more often due to lack of Ca than from the toxicity of Na. Increasing sodicity decreased the absolute Ca than from the toxicity of Na. Increasing sodicity decreases the absolute Ca concentration and Ca:Na ratio of the plant. In order to meet the Ca requirement of the plants and to lower the soil ESP to a threshold tolerance level of the crop, chemical or organic amendments are most commonly used.

Nutrient acquisition by plants in saline environment

Plants acquire mineral nutrients from their native soil environments. Most crop plants are glycophytes and have evolved under conditions of low soil salinity. Consequently, they have developed mechanisms for absorbing mineral nutrients in non-saline soils. Salinity in soil has a dual effect on plant growth via an osmotic effect on plant water uptake and specific ion toxicities (Sheldon *et al*., 2004). By decreasing the osmotic potential of the soil solution, plant access to soil water is decreased, because of the decrease in total soil water potential. In order to maintain water uptake from a saline soil, plants must osmotically adjust. This is done either by taking up salts and compartmentalizing them within plant tissue, or synthesizing organic solutes. Plants which take up salts generally have a higher salt tolerance and greater ability to store high salt concentrations in plant tissue without affecting cell processes, and are known as halophytes. Plants which synthesise organic solutes are known as glycophytes and they try to prevent excess salt uptake because they can tolerate much lower concentrations of salt in plant tissues before cell processes are adversely affected. Even with complete osmotic adjustment, a reduction in growth may occur due to the metabolic demands of maintaining osmotic adjustment.

Under saline conditions, which are characterized by low nutrient-ion activities and extreme ration of Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+} and Cl^-/NO^{3-}, nutritional disorders can develop and crop growth may be reduced. Addition of N and P generally increase the growth of plants grown in N- and P- deficient environments, provided that the plant is not experiencing severe salt stress. When salinity and nutrient deficiency are both factors limiting growth, relief of the most limiting factor will promote growth more than the relief of the less limiting factor. Therefore, addition of a limiting nutrient can either increase decrease or have no effect on relative plant tolerance to salinity, depending on the level of salt stress. Failure to account for the severity of salt stress when interpreting salinity x nutrient interactions has caused considerable confusion among researchers. According to Berstein*et al*. (1974) and Bernstein (1975), however, while N or P were severely growth limiting, salinity was found to affect to growth of some crops [broccoli (*Brassica oleracea* var. capitata), cabbage (*B. oleracea* var. botrytis)] less. Conversely, when salinity severely limited growth, nutritional responses of some crops decreased. Salinity did not aggravate N or P deficiency as judged by leaf N and leaf P contents. Effects of salinity and N or P deficiency on other mineral constituents were highly crop specific.

Salinity, however, disrupts mineral nutrient acquisition by plants in two ways. First, the ionic strength of the substrate, regardless of its composition, can influence nutrient uptake and translocation. Evidence for this is salinity-induced phosphate uptake in certain plants and cultivars. The second and more common mechanism by which salinity disrupts the mineral relations of plants is by reduction of nutrient availability by competition with major ions (i.e. Na^+ and Cl^-) in the substrate. These interactions often lead to Na^+ -induced Ca^{2+} and/or K^+ deficiencies and Ca^2+-induced Mg^{2+} deficiencies.

In sodic soils when pH of the soil solution exceeds 8.5, availability of some nutrients may be restricted resulting in nutrient imbalances. Bicarbonate toxicities occur primarily from reduced iron and other micronutrient availabilities at high pH while high Na^+ may lead to Ca^{2+} and Mg^{2+} deficiencies (Arshad, 2008). In sodic soil total soluble salt concentrations are low and consequently, Ca^{2+} and Mg^{2+} concentrations are nutritionally inadequate. The deficiencies rather than Na^+ toxicity are usually the primary influence on plant growth among the non-woody species (Maas, 1986).

Reclamation of sodic soils by gypsum

Mineral gyspum applied at rate of 12-15 Mg ha^{-1} (50% GR of 0-15 cm soil) is sufficient to initiate reclamation processes in rice based cropping system. Since alkali soils invariably contain $CaCO_3$, use of acids like H_2SO_4 or acid forming materials like pyrites (FeS_2) and elemental S are also helpful in supplying Ca ions through solubilisation of $CaCO_3$ and thus meet the Ca needs of plant and soil. The effectiveness of organic materials like FYM, pressmud, poultry manure, paddy and wheat straw, and green manures in reclaiming alkali soils and supplying Ca depends on the amount of CO_2 produced and reduced conditions through drop in redox potential under submerged conditions in rice culture. The increased P_{CO2} and reduced redox potential (Eh) of sodic soils help in solublising the native $CaCO_3$ and removal of Na from the exchange complex thereby improving the soil and inducing favourable ionic environment. Besides, application of these organic materials helps in reducing the gypsum requirement of alkali soil.

The availability of mineral gypsum and also manures are scarce these days. Further, the estimation of gypsum requirement of sodic soil is tedious and most of the soil testing laboratories either do not have facility for gypsum requirement or lack expertise in estimation, so a model was developed to estimate gypsum requirements based on soil pH value. The mobile application "GypCal" in English and Hindi was developed on android platform to promote judicious use of chemical amendment gypsum for reclamation of sodic soil using soil pH (Arora 2021) as input and this application is made freely available for download through google play store on any smart phone or tab.

Mobile App "GypCal"

Nitrogen management:

Most crops in sodic soils invariably suffer from inadequate N supply. Nitrogen transformations are adversely affected by high pH and sodicity, thereby affecting the efficiency of applied N. On flooding the soil, mineralization of organic nitrogen takes place and is limited to ammonification stage due to depletion of oxygen. Hence, ammonium is the form of mineral nitrogen that accumulates and is subjected to major loss (10-60% of applied fertilizers) through volatilization. Nitrification and urease inhibitors except phenyl-phosphorodiamidate (PPD) had little effect on urea hydrolysis and ammonia volatilization from slow release and urea fertilizer during rice culture in alkali soils. Since these soils are highly deficient in organic matter and nitrogen, it is recommended that during the first few years after reclamation crops be fertilized with 25% more nitrogen compared to recommended dose for normal soil. Split application of nitrogen through urea (1/3rd as basal, 1/3rd each at 21 and 45 days crop growth) should be followed. In rice, the basal dose of urea should be applied before puddling under pre-submerged conditions to reduce ammonia volatilization losses and enhance nitrogen use efficiency. Further studies showed that ammonia volatilization losses decreased significantly when FYM or green manure was combined with urea-N application as compared with urea-N alone. Numerous experiments have shown that recovery of fertilizer nitrogen normally ranges from 30 to 40% for rice in alkali soils. The efficiency of applied N in rice generally ranges from 25 to 45 per cent as compared with 50 to 70 per cent in upland crops. Proper management of fertilizer N is thus necessary for better N use efficiency. Under such situations nitrogen use-efficiency can be increased by integrated use of organic and inorganic sources of N.

Phosphorus management:

Uncultivated barren alkali soils contain high amounts of available P. When alkali soils were reclaimed by using amendments and growing rice under submerged conditions, Olsen’s extractable P of surface soil decreased due to its movement to lower subsoil layers, uptake by the crop and increased immobilization. Results of a long-term fertility experiment conducted on a gypsum-amended alkali soil (texture loam, pH 9.2; ESP 32) with rice-wheat and pearl millet-wheat cropping sequence and NPK fertilizer use showed that phosphorus applied at a rate of 22 kg P ha^{-1} to either or both rice and wheat crop in rotation significantly increased the grain yield of rice (Swarup and Yaduvanshi, 2004). In such soils, single superphosphate (SSP) is a better source of P than other phosphatic fertilizers because of high Na of alkali soils and that it contains appreciable some amount of calcium sulphate. Continuous use of fertilizer P, green manuring and FYM to crops significantly enhanced the yield of rice and wheat and improved available P status of the gypsum amended alkali soils. Alkali soils of Indo-Gangetic plains generally contain very high amounts of available K.

Therefore, crops do not respond to applied K even after 20 years of rice-wheat and pearl millet-wheat cropping systems in alkali soils (Swarup and Singh, 1989; 1994).

Management of micro nutrients:

Zinc deficiency is very common in rice grown on alkali soils. It is essential to apply 40 kg zinc sulphate per ha to rice for first few years and then it should be applied on soil test basis. Application of FYM, pressmud, poultry manure and Sesbania green manure also mitigates the Zn deficiency to great extent. Integrated use of Zn and FYM is more effective in ameliorating Zn deficiency as compared to $ZnSO_4$ alone, root dipping, zinc sprays and zincated urea. Farmyard manure, organic residues and green manuring help in increasing the productivity because of the nutrients they contain and also hasten the reclamation process. Therefore, it is extremely important to integrate the use of organic resources and chemical amendments. The alkali soils are rich in total Fe and Mn but are generally poor in water-soluble plus exchangeable and reducible forms of Fe and Mn. Soluble Fe and Mn salts, when applied to alkali soils, are rendered unavailable because of rapid oxidation and precipitation. Thus, higher amounts of Fe and Mn salts are needed to correct the deficiencies or to have beneficial effect on crop growth. Addition of FYM, rice husk and green manures was reported to enhance the available Fe and Mn by 10 to 15 times, with corresponding decrease in reducible forms (Swarup and Yaduvanshi, 2004).

Excess soluble salts in the soil solution of saline soils adversely affect the availability of nutrients to crops. Ionic imbalance and/or nutrient stresses are therefore important limiting factors for crop production. Application of 150 kg N, 60 kg P_2O_5 and 50 kg K_2O ha^{-1} are recommended for wheat crop whereas other crops require 120 kg N, 40 kg P_2O_5 and 40 kg K_2O ha^{-1} for sustained productivity. Split application of nitrogen through urea (1/3rd as basal, 1/3rd each at 21 and 45 days crop growth) should be followed. Both P and K fertilization of crops in saline soils helps in alleviating adverse effects of salinity and improving water and N use efficiency. Because of presence of Cl^- and SO_4^{-2} of Na, Ca and Mg salts, these soils are well supplied with secondary nutrients and crops do not require outside application. In general micronutrient deficiencies have not been widely reported in saline soils. However, crops grown in reclaimed saline soils under sub-surface drainage may benefit from the application of some micronutrients, which become deficient on account of post reclamation.

Halophilic microbial formulations for enhancing crop productivity under salt stress

Soil sodicity is one of the most adverse environmental factors responsible for limiting the productivity of crop plants. Sodic soils are inherently low in organic matter, available Nitrogen and Phosphorus. These soils are more prone to N losses due to higher N volatilization caused by high pH, further aggravating N deficiency. Microbial activity, which influences N mineralization, is restricted by salt stress (Abrol *et al*., 1988; Liu and Kang, 2014; Wong *et al*., 2010). Other than nitrogen, soluble P is often the limiting mineral nutrient for biomass production (Hameeda *et al*., 2006).

The microbial strains available as bio-fertilizers for different crops do not perform effectively under salt stress and their activity decreases when used in salt affected soils due to osmolysis (Arora *et al*., 2014). The soils of vast areas of country are sodic or saline sodic and these soils have low productivity due to poor physical and bio-chemical properties including low nutrient status. Physical and chemical methods of their reclamation are not cost-effective and also the availability of gypsum or other chemical amendments is a problem.

Halophilic microbial formulations developed by ICAR-CSSRI, RRS, Lucknow

Excess accumulation of salts hampers the growth and activity of soil microflora. It affects the growth of N_2 fixing and phosphate solubilising bacteria which led to low fertility of soils. Due to increased quantity of salts, the microbial flora is worst affected, this also interfered with nitrogen fixing and phosphate solubilising ability of bacteria. The applications of salt tolerant plant growth promoting bacteria include recovery of salt affected soils and indirectly help in increasing crop production (Arora and Sahni, 2019). They also enhance production of organic acids.

The advanced microbial technology for bioremediation of salt affected soils through salt tolerant (halophilic) bacterial strains of N fixers, P and Zn solubilizing bacteria have been developed by ICAR-CSSRI, RRS, Lucknow. These strains were characterized for plant growth promotion and tested for their efficacy under different levels of salt stress. To enable the seed application of these promising selected strains of beneficial soil microorganisms, these were made available as liquid bioformulations viz. Halo-Azo, Halo-PSB and Halo-Zinc. These can be used either for seed treatment or soil application. Application of these bioformulations helps to generate plant nutrients like N, P and

Zn through their activities in the soil or rhizosphere and make available to plants in a gradual manner under salt stress (Arora, 2020). These have been effective in improving yield of rice, wheat, mustard, vegetables and pulses in normal as well as salt affected soils and effective in soil health management to promote organic farming.In Unnao district, it has been reported thatco-inoculation of Halo-Azo and Halo-PSB in rice under sodic conditions resulted in higher yield and improvement in soil properties (Sahay *et al*., 2018).Similarly, in wheat, both bioformulations significantly increased the different growth parameters and yield of the crop as compared to control. The increase in wheat grain yield was 13.06 % higher with the inoculation of both bioformulations as compare to 7.7% and 9.3% increase with the solo inoculation of Halo-Azo and Halo-PSB over control. It has been inferred from the experiment that exploitation of halophilic bioformulations as biofertilizer with salt tolerant verities of rice and wheat has enormous potential in utilization of unfertile sodic land for food security, environmental health and economic welfare of farmers.

Effect of integrated use of liquid bio formulations Halo-Azo, Halo-PSB and Halo-Zinc with 75% of recommended dose of NPK showed 6.7% increase in grain yield of salt tolerant short duration variety of paddy grown on sodic soil of pH 9.6 over 100% recommended NPK and zinc sulphate. At different sodicity levels, it was observed that there was significantly at par yield of paddy (variety CSR46) at pH 9.4 when 75% recommended NPK along with Halo-Azo, Halo-PSB and Halo-Zinc were inoculated and when 100% recommended NPK with zinc sulphate was applied (Table 1). In coastal saline soils, highest grain yield of 5.12 t ha^{-1} of rice variety 'Sumati' was reported with combined application of liquid bio formulations Halo-Azo and Halo-PSB compared to grain yield of 4.69 tha^{-1} in un-inoculated control, indicating yield enhancement of 9.1% (Sarangi and Lama, 2018).An on-farm trial was conducted at KVK Hardoi during Kharif 2017 and 2018 to evaluate the performance of liquid bioformulation (Halo-Zinc) by treating seeds of paddy variety NDR 3112 in partially reclaimed sodic soils (Mishra *et al*., 2020). It was observed that the seed treatment with Halo-Zinc showed higher average grain yield (46.05 q ha^{-1}) and average straw yield (67.6 q ha^{-1}) as compared to the farmers' practice (T1 with no seed treatment). No zinc deficiency symptoms were observed in treated seeds plots due to enhanced availability of zinc. The B: C ratio was (1: 2.75) higher compared to the farmer's practice (1:2.45).

Table 1. Effect of bioformulations on performance of paddy in sodic soil

Sodic soil	100%RDF+25kg $ZnSO_4$ ha^{-1}	75% RDF+ Halo-Azo+ Halo-PSB	75%RDF+ Halo-Azo+ Halo-PSB+ Halo-Zinc
pH=8.8	56.5	52.6	55.4
pH=9.0	52.2	51.9	54.1

pH=9.2	44.8	41.9	42.3
pH=9.4	39.7	38.6	40.6
Mean	48.3	46.3	48.1
CD (5%)	1.46		

Liquid bioformulations were used in different crops on farmers' field at Hasanganj, Auras, Rashidpur in Unnao district on sodic soil (pH 8.6 to 9.4) it was observed that crop yield was enhanced in the range of 8.8 to 26.3%. Field pea seed inoculation with liquid bioformulations Halo-Azo+PSB+Zinc resulted in increase of 9.5 to 26.3% as compared to non-inoculation (Table 2). Similarly, seedling dip of onion with liquid bioformulations Halo-Azo+PSB+Zinc was found to enhance the yield upto 73.7 q/ha compared to maximum of 65.3 q/ha where no inoculation was done. Mustard seed treatment with liquid bioformulations Halo-Azo+PSB+Zinc, resulted in increase of yield by 11.4 to 18.7% compared to no-inoculation control.

Table 2. Performance of different crops at farmers fields in sodic soils [Soil pH 8.6 to 9.4]

Crop	Yield without bioformulations	Yield with Halo-Azo+Halo-PSB+Halo-Zn	% increase
Field Pea (n=15)	19.2 to 21.7 q/ha	22.3 to 25.4 q/ha	9.5 to 26.3%
Onion (n=7)	62.4 to 65.3 q/ha	68.2 to 73.7 q/ha	8.8 to 12.3%
Mustard (n=3)	16.4 to 18.1 q/ha	18.8 to 19.5 q/ha	11.4 to 18.7%

Conclusions

Management of salt affected soils should aim at realization of production potential either by addition of amendments or manipulation of agricultural practices to enhance the fertilizer use efficiency and higher crop yields. However, application of lime or FYM along with recommended dose of NPK is quite promising in maintaining stability in crop production through correction of marginal deficiencies of secondary and micronutrient elements. In sodic soils, application of gypsum has been effective in increasing the productivity. Split applications of N with 25% more of recommended dose and integrated nutrient management has been effective in enhancing the crop productivity and N use efficiency. Use of fertilizer P, green manures and FYM is effective in enhancing the yield of rice and wheat and improved available P status of the gypsum amended alkali soils. Alkali soils of Indo-Gangetic plains generally do not require accretion of K from external sources. Supplementation of Zn, Fe and Mn through inorganic and/or organic sources is required for maximizing the productivity of crop and cropping systems in alkali soils. In saline soils, leaching of soluble salts and application of fertilizers to supply nutrients is necessary in addition to salt tolerant varieties. Halophilic plant growth promoting bacteria have potential not only to alleviate stress in rhizosphere but also enhances nutrient availability for crop growth.

References

Abrol, I.P., Yadav, J.S.P. and Masood, F.I. (1988). Salt affected soils and their management. *FAO Soils Bull*., 39, 119.

Arora Sanjay (2020). Halotolerant microbes for amelioration of salt affected soils for sustainable agriculture. In:**Kumar**, Manoj, **Kumar**, V., **Prasad**, Ram (Eds.) Phyto-Microbiome in Stress Regulation, Springer, Singapore, ISBN: 978-981-15-2576-6, 323-343.

Arora, Sanjay (2021) Microbial approaches for bio-amelioration and management of salt affected soils. In: Soil Science: Fundamentals to Recent Advances (Rakshit, A., Singh, S.K., Abhilash, P.C. Biswas, A.), Springer, Singapore, pp. 433-447.

Arora S, Vanza Meghna J., Mehta, R., Bhuva, C. and Patel P N. (2014). Halophilic microbes for bio-remediation of salt affected soils. African *Journal of Microbiology Research* 8(33): 3070-3078.

Arora, Sanjay and Sahni, D. (2019) Halophilic microbe interactions with plants to mitigate salt stress. In: Akhtar (Eds), Salt Stress, Microbes, and Plant Interactions: Causes and Solution. Springer, Singapore, pp 249-272.

Arshad, M.A. (2008) Soil salinity and salinzation. In: Encyclopedia of Soil Science (Ward Chaseworth, ed.), Springer, The Netherlands, pp 699-703.

Bernstein, L., Francois, L.E. and Clark, R.A. (1974) Interactive effects of salinity and fertility on yield of grains and vegetables. *Agronomy Journal* 66: 412-421.

Bernstein, L. (1975) Effects of salinity and sodicity on plant growth. *Annual Review on Phytopathology* 13: 295-312.

FAO(2008). Land and plant nutrition management service. htpp://www.fao.org/ ag/agl/agll/spush.

Flowers, T.J., Garcia, A., Koyama, M. and Yeo, A.R. (1997). Breeding of salt tolerance in crop plants—the role of molecular biology. *Acta Physiol. Plant* 19: 427– 433.

Hameeda, B., Harmi, G., Rupela, O.P., Wani, S.P. and Reddy, G. (2006). Growth promotion of maize by phosphate solubilizing bacterial isolate from composts and macrofauna. *Microbiol* 59: 23-147.

Liu, S.H. and Kang, Y.H. (2014). Changes of soil microbial characteristics in salinesodicsoils under drip irrigation. *J. Soil Sci. Plant Nutr*. 14: 139–150.

Maas, E.V. (1986) Salt tolerance of plants. *Applied Agricultural Research* 1: 12-26.

Mishra, D.K., Arora, Sanjay and Gautam, C.P.N. (2020). Assessment of microbial bioformulation Halo-Zinc on performance of paddy in partially reclaimed sodic soils of Hardoi, Uttar Pradesh. *Journal of Soil and Water Conservation* 19(4): 421-425.

National Remote Sensing Application and Associates (NRSA & Associates) (1996). Mapping of Salt Affected Soils of India.1:250000 map sheets, legend. NRSA Hyderabad, India.

Sahay, R., Singh, A.K., Arora, S., Singh A, Tiwari, D.K., Maurya, R.C., Chandra Vikash and Singh, S. (2018). Effect of halophilic bioformulations on soil fertility and productivity of salt tolerant varieties of paddy in sodic soil. *International Journal of Current Microbiology and Applied* Sciences 7(9): 1174-1179.

Sarangi, S.K. and Lama, T.D. (2018) Evaluation of microbial formulations for crop productivity and soil health under coastal agro-ecosystem. ICAR-CSSRI Annual Report 2017-18, ICAR-CSSRI, Karnal, India, pp.165-166.

Sheldon Anna, Menzies Neal, W., Bing, S.H. and Ram, D. (2004) The effect of salinity on plant available water. Super Soil, 3rd Australian New Zealand Soils Conference, University of Sydney, Australia, pp 5-9.

Singh, Y.P., Singh, R. and Sharma, D.K. (2010). Determination of time frame for substitution of salt tolerant varieties of rice and wheat for productivity enhancement of sodic soils. *Indian Journal of Agricultural Science* 80 (7): 245-250.

Swarup, A. and Singh, K.N. (1989) Effect of 12-years rice-wheat cropping and fertilizer use on soil properties and crop yield in a sodic soil. *Field Crops Research* 21: 277-287.

Swarup, A. and Singh, K.N. (1994) Effect of gypsum, farmyard manure and nitrogen on ameliorating sodic soil and on yield of rice and wheat. *International Rice Research Notes* 19(3): 22-23.

Swarup, A. and Yaduvanshi, N.P.S. (2004) Nutrient stress management for sustaining crop productivity in salt affected soils. CSSRI Bulletin No 1/2004, CSSRI, Karnal.

US Census Bureau, 1998. www.census.gov/ipc/www/wp98001.html (July 30,2008)

Wong, V.N.L., Greene, R.S.B., Dalal, R.C. and Murphy, B.W. (2010). Soil carbon dynamics in saline and sodic soils: a review. *Soil Use Manag.* 26: 2–11.

Soil Organic Carbon Research – Issues to Ponder Over

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Soil organic carbon (SOC) is the foundation of almost all the ecosystem services offered by soils. Since long, scientists have, therefore, been engaged to elucidate its role in different processes involved in offering those services including agronomy, soil fertility and currently climate change. Enhancement or even maintenance of SOC stocks is difficult particularly in our tropical and sub-tropical regions. To do it, a few important challenges need to be addressed for soils under the regions. Of these, determining SOC through a simple, high throughput and cost-effective method, and its critical limits for upkeeping soil health and its ecosystem services under different agro-ecological zones of the country are paramount. Again, the amount of carbon to be added into soils for causing a zero change in SOC is also important. Identification of crops or cropping systems and management practices that could add sufficient amounts of C to cause such changes in SOC is a way out. Further, in many cases, it is observed that in spite of adding lot of crop residues C, there is hardly any increase in SOC stock, for example in conservation agricultural practices. Identification of processes and/or techniques facilitating conversion of these residue C to SOC is vital not only for enhancement of C in soils but also curbing CO_2 loading into atmosphere. An attempt is made in this lecture to highlight some of these issues for maintenance and, if possible, enhancement of SOC in soils under tropical and subtropical climatic conditions adopting farmers' friendly management practices.

Green Seeker based Nitrogen Management with Climate Resilient Agricultural Practices

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Intensive cultivation, growing of exhaustive crops, imbalanced and inadequate crop nutrition largely through chemical fertilizers has made the soils not only deficient in the nutrients but also deteriorated the soil health resulting in diminishing crop response to the recommended dose of nitrogenous fertilizer in the country. Non-judicious enhancement and its bias in favour of the N fertilization further worsen the situation. Evidence of declining partial or total factor productivity is already becoming evident. Decreasing soil fertility has also been reported as one of the major reasons for decline in crop yields. Fertilizer use pattern for rice in Rice-Wheat Cropping System in the Indo Gangetic Plains is region specific and diagnostic surveys have indicated that farmers are using more than the recommended levels of nitrogen to rice in Trans-Gangetic Plains and parts of upper Gangetic Plains representing Punjab, Haryana and Western Uttar Pradesh. Recovery of fertilizer N applied seldom exceeds 50% due to heavy losses through various means and lack of synchronization of crop requirement resulting in lower physiological efficiency. Food production is directly related to nutrient consumption, and N is the key element in the intensive cropping systems. The farmers have also increased the fertilizer doses in their rice crops over the last decade. The farmers themselves adjust their nutrient management practices on the basis of their experiences, but scientific revision of recommendation is yet to come.

Climate-Resilient agriculture (CRA) Program

Climate-resilient agriculture (CRA) is one such multi-benefit approach for transforming and reorienting agricultural development under the new realism of climate change. It may be defined as agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes GHGs where possible (mitigation), and enhances achievement of national food security and sustainable development goals. Several interventions can be made to build soil carbon, control in soil loss due to erosion and enhance water holding capacity of soils, all of which build resilience in soil. The climate smart interventions include interventions that might be either, water, nutrient, carbon, energy, weather or knowledge smart. Water stress tolerant cultivars and management approaches such as - Direct seeded rice, raised beds, precision land levelling, bunding, micro-irrigation, irrigation scheduling, residue mulching, rejuvenation of water structure/ bodies, technological interventions for improving conveyance efficiency are considered water smart. Nutrient smart interventions include Biofortified varieties, legume based cropping systems, SSNM and use of tools such as GreenSeeker, LCC and SPAD meter. No-tillage, residue management, agroforestry and boundary plantation of perennial horticultural crops can be considered as carbon smart. Cropping system optimization with no tillage and residue management are considered as energy smart. Weather forecast, Index based insurance, seeds for needs, crop diversification and contingent seed systems are weather smart technologies. Using ICTs, capacity development and innovation hubs are considered as knowledge smart systems.

Initiation of Climate Resilient Agriculture in *Jal-Jivan-Hariyali* mission

Under the Bihar government's initiative of Agricultural Road Map, climate change is identified as one major challenge for a sustainable agricultural growth in the state. Accordingly, the State government has started a series of innovations such as *Jal-Jivan-Hariyali*, Organic Agriculture Mission, Hariyali Mission, Crop Residue management and the Climate Resilient Agriculture programme. The climate resilient agriculture (CRA) program aims to provide climate smart science based solutions to the hard working farmers of Bihar. Based on the existing climatic situations, different ecologies (low, mid and upland soils) and available resources, 14 different cropping systems (Rice – Wheat – Mung bean; Rice – Wheat; Rice – Potato + Maize; Rice – Winter maize; Rice – Mustard – Mung bean; Rice – Lentil; Maize – Wheat – Mung bean; Maize – Mustard – Mung bean; Maize – Lentil – Mung bean; Soybean – Winter maize; Soybean – Wheat – Mung bean; Pearl millet – Mustard – Mung bean; Pearl millet – Lentil – Mung bean; and Pearl millet – Wheat – Mung bean) have been identified to be demonstrated in the 38 project districts of Bihar. However, irrespective of the cropping systems and the climate resilient agricultural practices being followed, Nitrogen is the most limiting nutrient in crop production, though more so, in irrigated cereal-based cropping systems. Traditionally, farmers apply N uniformly as a blanket recommendation in wheat crop. Mostly farmers apply N much higher than the blanket recommendation to get high crop yields. But large temporal and field to field variability of soil N supply restricts efficient use of N fertilizer. In this situation the site-specific N management can effectively replace the blanket fertilizer N recommendations for achieving high N-use efficiency and also reduced possibility of fertilizer N related environmental pollution. It appears that high fertilizer N-use efficiency can be improved through field-specific fertilizer N management because it deals with both spatial and transient fluctuation in soil N supply. There are various methods of nitrogen application with real time decision support such as leaf color chart, soil plant analysis development meter or chlorophyll meter and GreenSeeker. GreenSeeker is an integrated optical sensor based with variable rate application and mapping system which measures the crop's nitrogen requirements. The technology was developed at Oklahoma State University, USA and licensed to N Tech Industries in 2001 (www.ntechindustries.com). The sensor uses light emitting diodes (LED) to generate red light (660 nm) and near infrared light (780 nm). Red light is absorbed by plant chlorophyll as an energy source during photosynthesis. Healthy plants absorb more red light and reflects larger amounts of near infrared light NIR. The biomass produced per day as estimated through NDVI measurement using optical sensor is a reliable predictor of yield potential.

Nitrogen fertilizer that is applied at the optimal time will maximize the plant's uptake, which enables to reduce the amount of fertilizer used (without decreasing yield) and decreases N_2O emissions. Traditionally, farmers in the Indo-Gangetic plains of South Asia and elsewhere apply nitrogen uniformly as a blanket application based on the state recommendation for most of the crops. Such broad-based 'blanket' recommendations of fertilizer Nitrogen (N) restrict efficient N use, and recovery of N fertilizer. Therefore, under and over application of N is a common phenomenon, which limits the crop yields in agriculture system. Current fertilizer N recommendations (amounts and timings) are based on large agro-ecological regions of rice and wheat growing tracts in IGP and does not account for spatial and temporal variability of the field. It is important to know about the amounts and variations in the indigenous N supply during crop season, to determine the optimal timing and amount of fertilizer N applications in any crops and cropping system. Since indigenous N supply is highly variable over time, in same as well as different fields, in any given agro ecological region it is not easy to precisely manage N requirements of the crop plants. Innovative fertilizer management practices aimed at managing N efficiently, must integrate both preventive and corrective strategies, to sustain the soil resource base and increase the profitability of irrigated rice and wheat crops grown in the IGP.

Green Seeker is an integrated optical sensing and application system, that offers more efficient and precise way of instant fertilizer application. Green Seeker is an affordable and innovative diagnostic tool that can be used to assess the heath or vigor of a crop. Green Seeker is based on the measurements of reflectance in the red (defined by chlorophyll content) and near infrared (defined by living vegetation) region of the electromagnetic spectrum for estimating N requirement of crops using early season estimates of N uptake and potential yield. In this technology the yield potential for a crop is identified using a vegetative index known as NDVI (Normalized Difference Vegetative Index), and an environmental factor. Nitrogen (N) is then recommended based on yield potential, and the responsiveness of the crop to additional nitrogen. Fertilizer N use efficiency can be improved through Site Specific Nutrient Management (SSNM) using Green Seeker, as it takes care of both spatial and temporal variability in soil N supply. Urea Calculator android app (available in English, Hindi and Punjabi language) on a smart phone or tablet are used to calculate N fertilizer application rates from crop readings taken with the Green Seeker.

Plant reflectance and normalized difference vegetation index (NDVI)

Reflectance is the ratio of energy that is reflected from an object to the energy incident on the object. Spectral reflectance of a crop differs considerably in the near infrared region (λ = 700-1300 nm) and in the visible red range (λ = 550-700 nm) of the electromagnetic spectrum. Plants generally have low reflectance in the blue and red portion of the spectrum because of chlorophyll absorption, with a slightly higher reflectance in the green, so plants appear green to our eyes. Near infrared radiant energy is strongly reflected from the plant surface and the amount of this reflectance is determined by the properties of the leaf tissues: their cellular structure and the air-cell wall-protoplasm-chloroplast interfaces. These anatomical characteristics are affected by environmental factors such as soil moisture, nutrient status, soil salinity, and leaf stage. The contrast between vegetation and soil is at a maximum in the red and near infrared region. Therefore, spectral reflectance data can be used to compute a variety of vegetative indices that are well-correlated with agronomic and biophysical plant parameters related to photosynthetic activity and plant productivity. The NDVI is successful in predicting photosynthetic activity, because this vegetation index includes both near infrared and red light. Plant photosynthetic activity is determined by chlorophyll content and activity. The relationship between leaf N and leaf chlorophyll has been demonstrated for maize.

The NDVI is calculated from reflectance measurements in the red and near infrared (NIR) portion of the spectrum:

$$NDVI = \frac{R_{NIR} - R_{\mathrm{Red}}}{R_{NIR} - R_{\mathrm{Red}}}$$

where:

R_{NIR} is the reflectance of NIR radiation,

R_{Red} is the reflectance of visible red radiation.

The NDVI has been correlated to many variables such as crop nutrient deficiency, final yield in small grains, and long-term water stress. However, rather than exclusively reflecting the effect of one parameter, NDVI has to be considered as a measurement of amalgamated plant growth that reflects various plant growth factors. The physical characteristics detected by the index are likely related to some measure of canopy density (i.e. leaf area or percent cover) or total biomass. Therefore, the underlying factor for variability in a typical vegetation index cannot be blindly linked to a management input without some knowledge of the primary factor that limits growth. For example, in a field where N is the limiting factor to growth, the NDVI may show a strong correlation with the N availability in the soil; however, in another field, where water is the limiting factor, the NDVI may be just as strongly correlated with plant-available soil moisture.

There are different vegetation indices; however, those that rely on NIR and red reflectance as their principal inputs will typically yield the same information as the NDVI. One of the reasons for the popularity of the NDVI is that many sensors (from handheld to satellite) provide measurements in the NIR and red portion of the spectrum. NIR is also used in color infrared photographs. Most, if not all, of the new commercial satellites will have red and NIR bands, so the availability of these data will increase.

Table: Yield and percent enhancement in yield of crops under GreenSeeker based Nutrient Management in Rice-wheat cropping system (2019-20 & 2020-21).

S. No.	Name of Technology	Average Grain Yield(q/ha)		Average Straw Yield(q/ha)		Harvest Index		% increase (yield)
		Demo	Local check	Demo	Local check	Demo	Local check	
1.	Green Seeker based Nutrient Management in paddy	43.90	36.70	55.30	45.50	44.25	43.26	16.40
2.	Green Seeker based Nutrient Management in wheat	41.88	36.39	62.20	52.90	40.23	40.75	13.10

Thus, GreenSeeker is is a non-destructive method for accurate estimation of required amount of nitrogen on the basis of plant condition as well as site specificity. A combination of prescriptive N dose at planting and crown root initiation stage and corrective N dose guided by GreenSeeker optical sensor at different stages of different crop holds promise in achieving high yield and N use efficiency. The biomass produced per day as estimated through NDVI measurement using optical sensor is a reliable predictor of yield potential. Green Seeker helps to produce the expected yield that is higher than the traditional method for application of nitrogen. Urea calculator app and N-rich plots are required to complement the actual dose of N application at right time. For initial doses of N, scheduling and amount of N fertilizer should be complemented to target the last dose of urea on green seeker readings basis. Apart from this, the green seeker guided nitrogen management practices, are compliant with zero till system coupled with precise water management technologies, for harnessing the best benefits. Good agronomic, soil and crop management practices always have synergistic effect on saving of precious inputs.

Phosphorus Deficiency in Plants and its Amelioration

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Introduction

Phosphorus is the 2nd most limiting macronutrient for plant growth, after N. It ranks 11th in order of abundance in earth's crust. Phosphorus was first made by Hennig Brandt in Hamburg in Germany in 1669 and its essentiality to plants was discovered by C. Sprengel in 1839. It is taken up by plants mainly as dihydrogen orthophosphate ($H_2PO_4^-$) and mono hydrogen orthophosphate (HPO_4^{2}) ions depending on pH of the system. The total P in Indian soils ranges from 120-2166 mg/kg. Nutrient use efficiency of P is only 15% rest remains as fixed form in mineral lattices. Like C and N, P do not have any atmospheric reserve. Main source of P is weathering of rocks and minerals. That is why careful management of this nutrient is very much necessary for sustainable agricultural development**.**

Role of P in plants-

Major role of phosphorus in plants is energy transformation. Besides the other function in which Phosphorus plays important role are are:-

- It gives structural support to the plant body.
- It takes part in energy generation and storage of ATP.
- It promotes root formation and growth of plant.
- Improves quality of fruit
- Stimulates flowering, seed setting and early maturity (grain crops).
- Helps in increasing root nodulation.
- Necessary for enzyme action of many plant metabolic processes.

Common deficiency symptoms of P-

Visually, P deficiency results in a reduced stature, acute leaf angles, suppression of tillering, prolonged dormancy, early senescence and decreased size and number of flowers and buds (Bould *et al.*, 1983). Symptoms of P deficiency occur first in older leaves. The development of dark green or blue green foliage is among the first symptoms of P deficiency. Red, purple or brown pigments develop in leaves, especially along veins. This is a consequence of anthocyanin production, which is induced by increased leaf sucrose concentrations (Muller *et al.*, 2005; Teng *et al.*, 2005)

P deficiency symptoms of some common field crops

1. Wheat

Plants are stunted and show purple tints on their dark green leaves, veins and stems. The older leaves, affected first, often senesce prematurely. Stems and leaves turning purple, a reduced root system and poor tillering are other common symptoms.

Figure 1 P-deficient

Figure 4 P-deficient

Figure 5 P-Sufficient

2. Maize

Symptoms of phosphorus deficiency are that young plants look dwarfed and thin with dark green leaves. Leaf margins, veins and stems show purple tints which may spread over the whole leaf blade. Phosphorus deficiency is also manifested by reddish discoloration at juvenile stages of growth.

Figure 6 P-deficient

Figure 7 P-Sufficient

Figure 8 P sufficient (left) and P deficient (right)

3. Mustard

Phosphorus (P) is important for the establishment of a healthy and robust root system. Deficiency will result in dwarfed plants with stunted roots. With severe deficiency, plants will be spindly, and if extremely deficient, mustard plants will have purple discoloration of the stems and leaves as well as be stunted.

Figure 9 P-deficient

Figure10 Deficiency (right) and sufficiency (left) of P in mustard

4. Tomato

Phosphorus deficiency tends to inhibit or prevent shoot growth. Leaves turn dark, dull, blue-green, and may become pale in severe deficiency. Reddish, reddish-violet, or violet color develops from increased anthocyanin synthesis. Symptoms appear first on older parts of the plant. New leaves usually appear healthy, but they are often small. Phosphorus deficiency also leads to increased root to shoot ratio in many plant species.

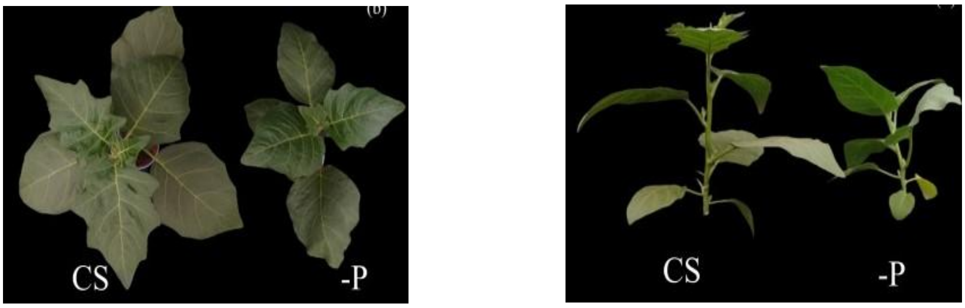
Figure 11 P-deficient

Figure 12 P-deficient

Figure 12 P- sufficient

5. Brinjal

Stunted growth of plants, but they remained normal green in colour. Leaves are smaller in size and turn dirty greyish green, with patches and shed prematurely, resulting bare stem in lower parts of the plant. The fruits are small, pale in colour and mature early.



Complete nutrient solution (CS) compared with P deficient (-P) solution

6. Cotton

Symptoms include smaller, very dark green leaves, with purplish reddening. Other possible symptoms are overall stunting, poor boll retention, and delayed flowering. Regardless of how the in-season symptoms are expressed, the ultimate consequence of P deficiency is yield reduction.

Figure 15 P-deficient

Figure 16 P-deficient

Figure 17 P-Sufficient

7. Soybean

Stunted plants and leaves with dark green, purple, or bluish tint appear when P is deficient. Root development may not be extensive. Because P is mobile within the plant, symptoms are generally more severe on lower leaves.

Figure 18 P-deficient

Figure 19 P-deficient

Figure 20 P-Sufficient

Amelioration of P-deficiency

Sound P-management strategies should be followed in order to ameliorate P deficiency from crops. This includes-

- Liming of Acid soils

It reduces the fixation loss and the fertilizer P remains in soluble form for longer period.

- Treatment of planting materials

Root dipping and seed treatment with soluble P sources can enhance P-use efficiency thereby eliminating deficiency in field crops.

- Mycorrhizal fungi

These colonize in the roots and besides acting as a root extension, acts as mobilizer of P in low P soils.

- P solubilizing microbes

These helps in dissolution of P from insoluble phosphate rocks and minerals e.g- *Bacillus megaterium, Pseudomonas striata*

P fertilizers

Phosphatic fertilizer can broadly be classified into three categories namely

1. Water soluble phosphatic fertilizer
2. Citrate or acid soluble phosphatic fertilizers and
3. Insoluble phosphatic fertilizer

Water soluble phosphatic fertilizers (Single super phosphate, Double super phosphate, Triple super phosphate) are recommended for neutral to slightly alkaline soil condition whereas acid soluble fertilizers (Di-calcium phosphate, Basic slag, Pelophos, Bone meal) are recommended for acidic soil condition depending on their solubility after soil application.

Method of application of phosphatic fertilizer

Generally the full dose of phosphorus fertilizer is applied as basal at the time of planting. It is done because Phosphorus is involved in healthy root growth of plants and plants are most responsive to Phosphorus application up to the initial 40 to 45 days.

It is generally applied near the root zone of plants (localised placement or band application) to avoid the maximum possible contact with the soil particles to minimize the fixation loss. For increasing the Phosphorus use efficiency, foliar application of phosphorus with water soluble Phosphatic fertilizer is also being done now a days.

Main reason for Phosphorus mining from soil

Nutrient mining is the negative balance of nutrients in which elevated loss of nutrients from soil occur over its addition into it. P as a nutrient is subjected to heavy mining from soil and as a result have become a yield limiting element.

Main reason behind P mining from soil are-

- ➢ Crop uptake
- ➢ Fixation loss
- ➢ Soil erosion due to run-off
- ➢ Removal of crop residues
- ➢ Imbalanced fertilization

Latest technologies to improve Phosphorus use efficiency

- Biofertilizers (P-solubilizers and mobilizers)
- Integrated nutrient management
- Crop residue management
- Site specific nutrient management
- 4-R nutrient stewardship approach
- Diagnosis and recommendation integrated system

Conclusion

Phosphorus due to its tendency to react with various soil components is very much prone to various types of losses and as a result has become a yield limiting nutrient in most of the crop lands. So careful management of these essential nutrient is very much important to ensure sustainable agricultural development.

Phosphorus Chemistry in Soils: Better Management Strategies for Higher Productivity

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Introduction

Phosphorus (P), next to nitrogen, is the second most important macronutrient that significantly affects multitude life processes, including photosynthesis, respiration, energy generation, nitrogen (N) fixation, nucleic acid synthesis, glycolysis, enzyme activation/ inactivation, redox reactions *etc*. Phosphorus nutrition benefits plants in terms of flowering, fruiting, shoot and root growth. Phosphorus is scarce element in biosphere and it stands at eleventh place in lithosphere in terms of its content. The soil-P can be broadly grouped into organic and inorganic form. The soil solution P (Pi) in a fertile soil is less than 10 µM even at favourable pH of 6.5. Inorganic phosphate is largely not available for uptake by the plant roots due to unique properties of P slow diffusion rate at plant-soil interface and high chemical fixation in soils (Vijay *et al*., 2018). Low P availability limits plant growth on many soils and is a common constraint to agricultural productivity. Use of P fertilisers is necessary for most of the agricultural systems to overcome soil P deficiency. Thus, phosphorus application helps to achieve both food production and nutrition security. However, the P-resources are non-renewable and finite. Thus, sustainable and equitable use of P resources in agriculture is important and there is a need to improve the efficiency of P fertilisers among different agricultural systems. It is estimated that the P-reserves would get exhausted by 2070. The present diversion of nutrients from food crops to energy crops may even worsen the nutrient scarcity.

Phosphorous chemistry

Phosphorus is one of the major plant nutrients that is least available in soils. In most soils, its availability is very low (~ 2 µM) while, its concentration in plants is much higher (5-20 µM). Its deficiency can significantly affect both growth and metabolism in plants. The crop productivity is severely lost especially in highly weathered soils of humid tropics and sandy soils of semi-arid regions. The solution phosphorus (Pi) is present mostly in $H_2PO_4^-$ and HPO_4^{2-} forms and their content is largely regulated by its interaction with organic and inorganic soil colloids. At the same time, much of it exists in organic form and becomes available through mineralization. Unique and high reactivity of Pi with other elements fix the applied Pi to an extent of 80 per cent. Plants must also compete with microbes to get their Pi under nutrient limiting conditions. Thus, farmers apply 4 to 5 times the quantity necessary for crop production. Contrastingly, intensive animal based agricultural systems threaten the ecosystem with excessive phosphorus. Under Pi-saturated conditions, plants have developed highly specialized physiological and biochemical mechanisms for enhanced uptake.

Phosphorus cycling in soil is a complex phenomenon that is strongly influenced by the nature of the inorganic and organic solids, chemistry of the soil solution, forms and extent of biological activity and other environmental factors (Pierzynski *et al*., 2005) Thus, the concepts of labile and non-labile P are mostly descriptive terms for convenience as chemistry of phosphorus is still less understood. The solution-Pi within a system is determined by chemical and biochemical processes *viz*. dissolution-precipitation, sorption-desorption, mineralization-immobilization and oxidation-reduction. However, erosion, surface runoff, leaching etc. can altogether set changes of higher magnitude. The sorption of phosphorus can be in absorption and adsorption processes. At a later stage, sorption can proceed to precipitation when solubility product constants are exceeded resulting in three-dimensional long range atomic ordering. Calcium, aluminium and iron are the primary cations involved in these reactions. The addition of phosphorus increases Pi in soil solution and then, precipitates primarily in adsorption and precipitation processes. Initially, the sorpted-Pi can be easily reversed. Later, these solid phases may later get converted to less soluble forms. Biological utilization of the nutrient converts Pi into organic-P in the form of inositol phosphates, phospholipids and nucleic acids (Raghothama *et al*., 1999).

Efficient phosphorus management is possible by simple 4 R’s approach – Right source, Right rate (quantity), Right time and Right Place will help to keep the nutrients on and in the field (Faucon *et al*., 2015). An attempt is made here to identify phosphorus management strategies to meet the above 4 R’s and later, categorize them into physical, chemical, biological and agronomic strategies and the options available are presented as points under each heading

Physical strategies

The P-fertilizers are available in different forms and with different solubility properties *viz.*, water soluble, citrate soluble and sparingly soluble. All P- fertilizers used either in direct phosphoric acid forms or its simple salts of ammonium, potassium, calcium etc. The following physical strategies will help for better P-management

- Size of the fertilizer compounds
- Altering the solubility of P-fertilizers
- Granulation of fertilizers
- Application in split doses
- Fertilizer placement at specified depths, distances and patterns (into root zone)
- Use of phosphoric acid directly with dilutions through fertigation

- Applying in right quantities at right time
- Use of nano P-fertilizers
- Foliar sprays at critical stages

Chemical strategies

The Pi is hightly reactive and it changes its redox status from +5 to -3 depending on soil condtions – Phosphate (+5), phosphite and phosphonate (+3), hypophosphate (+1) and phoshine (-3). However, the most common forms of Pi in soil utilized by plants are $H_2PO_4^-$ and $HPO_4^=$. High reactivity of Pi with Fe, Al and Ca result in respective precipitates. Thus, maintenance of pH, so as to reduce the activity of the metal ions, is very important for good P-management. Important chemical strategies which can be explored and adopted for better P-utilization are

- Use of rock phosphate in acid soil
- Maintaining the soil pH at slightly acidic condition
- Application of compatible fertilizers
- Reduce the activities of Fe and Al by liming, organic manures etc
- Phosphorus enrichment in organic manures
- Maintaining nutrient ratios in soil solution
- Granulation of P-fertilizers with organic manures
- Utilization of P from sewage and agro-industrial waste waters

Biological strategies

The concentration of Pi in soil is much lower than its concentration in plant tissues. The plants have evolved themselves to overcome the situation through root architecture, high root density, root secretions and development of special P-transporters on roots, microbial associations, inducing conditions for P-gradient within the rhizosphere, lateral branching of roots, lengthy root hairs etc., (Jakobsen *et al*., 2005). The following biological strategies appear to contribute for better P-management

- Selection of crops suitable after P-deficient environment
- Development of genotypes suitable for P-stressed environment
- Transfer of selective genes of P-transporters
- Plant – mycorrhizal associations
- Use of suitable P-solubilising microbial strains

- Application of genetic engineering tools to transfer specific genes responsible for P-mobilization
- Development and screening of genotypes with higher root:shoot ratios

Agronomic strategies

As discussed earlier, there are several physical, chemical and biological approaches to enhance phosphorus availability. Introducing them into location specific cropping system will undermine the possible benefits. Some of the important agronomic strategies to enhance P use efficiency in farming system are reduction of P losses, targeted use of sustainable P fertilizers, effective P-recycling in different cropping system and breeding for plant traits involved in maintaining productivity on low-P soils (Metson *et al*., 2016). Important agronomic strategies available for better P-utilization are

- Band / row/ ring placement is better than broadcasting
- Use of seed cum fertilizer drill
- Application of phosphorus after a week of sowing or transplanting
- Use of coated / granulated and slow-release fertilizers
- Addition of P in small doses to the rootzone through fertigation
- Reduced/ conservation tillage practices
- Compost enrichments – use of rock phosphate during composting
- Application of P through enriched composts
- Green manuring and crop rotations
- Use of agro-industrial / animal wastes- bone meal/ fish meal etc (other than dung)
- Cover crops helps to reduce erosion
- Soil conservation measures helps to retain phosphorus
- Residual crop or relay cropping systems especially in vegetable crops
- Preparation of P-balance sheets at landscape level for fine tuning nutrient movement

Conclusion:

With increasing population demand on land for food production, highly intensive cropping is gaining traction, which is directly dependent on current phosphate stocks, and measures should be devised to maximise resource utilisation and minimise phosphate loss from soil. Application, accumulation, control and transfer of phosphorus in intensive cropping systems has sparked global concern. Even though there has been a lot of study on P in the previous few decades, there is still a lack of knowledge on agricultural productivity and environmental quality. In order to increase P management and availability in agro-ecosystems, both technological and conceptual innovation is required. Management strategies should be designed in such a way that the technology is cost effective, environment friendly and finally, its adoption is simple to the farmers.

References:

Faucon, M. P., Houben, D., Reynoird, J. P., Mercadal-Dulaurent, A. M., Armand, R. and Lambers, H.2015, Advances and perspectives to improve the phosphorus availability in cropping systems for agroecological phosphorus management. *Adv. Agron.*, **134**: 51-79.

Jakobsen, I., Leggett, M. E. and Richardson, A. E. 2005, Rhizosphere microorganisms and plant phosphorus uptake. *Phosphorus: agriculture and the environment*, **46**: 437-494.

Metson, G. S., Macdonald, G. K., Haberman, D., Nesme, T. and Bennett, E. M. 2016, Feeding the corn belt: opportunities for phosphorus recycling in US agriculture. *Sci. Total Environ.*, **542**: 1117-1126.

Pierzynski, G. M., Mcdowell, R. W. andThomas Sims, J. 2005, Chemistry, cycling, and potential movement of inorganic phosphorus in soils. *Phosphorus: Agriculture and the environment,* **46**: 51-86.

Raghothama, K. G. 1999, Phosphate acquisition. *Annual review of plant biology*, **50:** 665-695.

Vijay, S. K., Janardan, L. and Dhurva, P. G. 2018, Strategies to Improve Phosphorus Availability in a Sustainable Agricultural System, *Int. J. Innov. Sci. Technol.*, **3**(9): 2456-2165.

Phosphate Fertilizers in the Era of Eco-Sensitive Farming

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Some of the greatest lessons we treasure from Covid-19 Pandemic are virtue of clean eco-system that are free from lethal biotic and abiotic substances. We are compelled to accept that the sanitation is the key to Geosphere (pedosphere + hydrosphere) - Biosphere – Atmosphere continuum and that it is intrinsic to interdependence of life-forms. We recognize that our survival rests on the virtue of immunity and for that matter, nutritious and safe food are indispensable. All these issues, perhaps focus more on phosphorus than any other plant nutrients.

Globally, P containing fertilizers are provenanced from Phosphate Rock (PR). About 90% of PR is used as fertilisers in agriculture (Brunner 2010 p. 870). While 52% of global phosphate mining is in China, 10% in the USA and 12% in Morocco (12%) (USGS 2019).Grantham (2012) and FAO (2004) feared that PR would be exhausted in the current decade around 2030.The fear has been slightly alleviated with the discovery of new reserves and reassessing existing resources. But, information on the occurrence and lifespan of PR reserve remains conflicting (Oloo and Asbon, 2020). Current geo-political situation show the vulnerability of India, which does not have any commercially significant PR resource. This highlights two challenging facets for the nation – deriving P-fertilizer from P-poor PR resources and recycling from soil and biotic sources, food wastage, and sewerage and sludge on urgent footing aptly supported with innovative technology.

Phosphate Rock takes millions of years to concentrate in the Earth’s crust and the resources are finite implying that they cannot be renewed like N fertilizer resources. All Phosphate Rocks, and products derived from them contain high amounts of heavy metals (e.g., Cd, Cr, Pb, Sb, V, Zn, and Cu), and radioactive elements (e.g., U, and Th) (FAO, 2004) and as a consequence they get accumulated in soils causing irreversible damage to the ecosystems. Conventional fertilizers including P-containing fertilizers are made up of salts; one component of which is plant-nutrient ion(s), while counter component is either not very useful or, toxic leading to irretrievable impairment to soils and food-quality resulting disastrous to human and animal health (Mukhopadhyay, 2014). Another disturbing fact is that the P-fertilizer use efficiency is only 10-25 percent, which might go down to <1% in alkaline calcareous soils (common in Bihar) when phosphate rock is applied.

Author attempted to address the above stated issues by three prong approach: (1) obtaining heavy metal and radionucleotide free materials through novel beneficiation process (Mukhopadhyay, 2014b), (2) assembling exclusive phosphate ion (PO_4^{3-}) ions in clay mineral receptacle (Mukhopadhyay, 2014c), and (3) innovate farmer-centric method for fabricating nano-fertilizer (Mukhopadhyay, 2014d).

Segregation of P-containing minerals devoid of toxic materials from phosphate rock (PR) ore was based on a set of physical non-destructive process that involved physical breakdown of large rock materials into smaller (sand size) parts accompanied by screening, followed by sink-or-float separation of heavy-metal free phosphorus-minerals from the sand size ore using desired specific gravity liquid that do not dissolve ore-materials (Mukhopadhyay, 2014b).

Novel nano-phosphorous products were manufactured by intercalating phosphate ion (PO_4^{3-}) in kaolin clay mineral. The nanoproducts, when applied to soil as fertilizer, would release either phosphate ions (PO_4^{3-}), or get converted to hydrogen phosphate ions (HPO_4^{2-}) or dihydrogen phosphate ions ($H_2PO_4^{-}$). All three forms are available to plants, and the release of phosphate ion would be through diffusion process. The novelty in this invention lies in resolving two contradictions in P chemistry in soil-plant system -between low solubility and excess application of P by opening new avenues to improve P use efficiency and reduce P build ups in soils and thereby reducing its load in surface water bodies and checking contamination in drinking water. The central idea was to the use of plant available form of P and making use of clay minerals as receptacles so that their quantum-mechanical function would overcome coagulation and conversion to insoluble forms, and their high energy would allow them to penetrate in the rhizosphere easily. The other proposition was to keep the ratio of applied and plant uptake P around unity by improving efficiency of native and applied phosphorus in soils, regulation of essential elements apart from elimination of toxic materials that are commonly associated with conventional phosphorous fertilizers. One of the crucial advantages of the nano-products is that both P forms and clay minerals are bio- and eco-safe.

The industrial processes of nanofabrication of materials/ matter involve a variety of physical and chemical techniques such as vapour deposition, laser ablation, arc discharge, lithography or nano-machining, nanoimprinting etc. to generate nanoproducts from bulk counterparts. These processes are complex, energy intensive and require highly sophisticated reactors. Moreover, industrially manufactured nanomaterials may not be compatible to the requirements of plants as nanoproducts of agricultural and managed-forest ecosystems have to address specific sequential functions like adsorption/ encapsulation followed by delivery of payload (e.g., fertilizer, plant nutrient, pesticide active ingredient, phytohormone) in the order of magnitude of plant-available forms and rate of demands of plant nutrients or other farm inputs, and also to ensure their uptake happens in ionic form(s). The materials nanofabricated by industry-centric processes are either in oxide form or, in zero-valent form, and hence, they might not be very desirable for applications in agriculture or in managed-forest ecosystems. Therefore, author invented a process for nanofabrication of desired material in the clay mineral receptacles for their potential primary applications as advance nanomaterials in agriculture. The process involved breakdown of bulk-form of clay-minerals along with the planes of weakness by physical top-down method to nano-form. This is followed by the transportation of desired ion/ ion pair (especially nutrient ion/ ions/ ion pairs) from solid to liquid phases, which occur through dispersion, and then intercalating them in group or, in sheet form into inter-lattice positions along 001 planes or, on broken bond sites. To avoid coagulation/ aggregate formation, the resultant product remained charged and in the dispersed state (Mukhopadhyay, 2014d).

Post-Covid scenario calls attention to an ecosystem compliable farming. Our conventional fertilizers are slowly losing relevance, but their replacements are sluggish to come. Nanotechnology as one of the technological tools and clay minerals as safe nano-materials bring new hopes in fresh advances and innovations. With well found PR ores, Bihar possibly is best suited to cradle the upcoming era in agriculture.

References

Brunner, P. H. (2010). Substance Flow Analysis as a Decision Support Tool for Phosphorus Management. *Journal of Industrial Ecology,* 14(6):870–873.

FAO (2004). Use of phosphate rocks for sustainable agriculture. Fertilizer and Plant Nutrition Bulletin # 13. Food and Agriculture Organization of the United Nations. Rome.

Grantham, J. (2012). Be persuasive. Be brave. Be arrested (if necessary). *Nature* 491:303.

Mukhopadhyay, S.S. (2014a) Nanotechnology in Agriculture: Prospects and Constraints. *Nanotechnology: Science and Applications***7**: 63–71.

Mukhopadhyay, S.S. (2014b) Beneficiation of phosphate rock for the segregation of phosphorus containing heavy metal free minerals. Indian Patent # 301187 (Granted on 19/09/2018).PCT International Patent Pub. No. WO/2015/159140; International Application No.: PCT/IB2015/000437; Publ. Date: 22.10.2015.

Mukhopadhyay, S.S. (2014c) Nanofabrication of phosphorus on kaolin mineral receptacles. Indian Patent # 316692 (Granted on 24/07/2019).PCT International Patent Pub. No. WO/2015/155585; International Application No.: PCT/IB2015/000439; Publ. Date: 15.10.2015.

Mukhopadhyay, SS. (2014d) Nanofabrication process involving clay minerals as receptacles for manufacturing advanced nanomaterials including novel fertilizers. Indian Patent # 372346

(Granted on 21/07/2021). PCT International Patent Pub. No. WO/2015/150903; International Application No.: PCT/IB2015/000433; Publ. Date: 08.10.2015.

Oloo, K.P. and Asbon, O. (2020) Depletion of phosphate rock reserves and world foodcrisis: Reality or hoax? *African Journal of Agricultural Research* 16(9):1223-1227. [DOI: 10.5897/AJAR2020.14892].

USGS (2019): Phosphate Rock. *U.S. Geological Survey, Mineral Commodity Summaries*, No.703, pp. 122–123.

Vaccari, D. A., and Strigul, N. (2011): Extrapolating phosphorus production to estimate resource reserves. *Chemosphere*84(6): 792–797.

Novel Phosphatic Fertilizers and Enriched Manures: Strategy to Increase Fertilizer Use Efficiency

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Fertilizers play a key role in agricultural production that relies on the use of inorganic fertilizers. However, major concern is the development of multi-nutrient deficiency and fertilizer-related environmental pollution. Similarly, increased prices of fertilizers pose search of alternative sources to supplement nutrient requirement of crops. Phosphorus (P) is the second major essential plant nutrients required for crop growth and productivity. It is the 11th most abundant element in the earth's crust, however its availability hardly exceeds 20% under best management practices. At present, diammonium phosphate (DAP) is the most important P-fertilizer in the world. However, for manufacture of P-fertilizers, India imports large amounts of premium-grade rock phosphate (RP) containing >30% P_2O_5 from other countries. Further, the cost of raw materials has increased many folds in recent times all over the world, so much so the cost of P-fertilizers has increased in India and poses a heavy burden on the economy. Therefore, research priorities have been directed toward finding alternative novel P-fertilizers and enriched manures for crop production. The aim of such investigations primarily revolved around the use of indigenous minerals such as low-grade RP as the source of P, which is of poor quality and not suitable as raw materials for conventional P-fertilizer production, but could be utilized if modified by chemical and biological means.

Organic manure application sustains cropping system through better nutrient recycling and improvement of soil physical properties. They are however, required in large quantities to meet up crops' nutrient demand. Fertilizers with available quantities of manure are now commonly used to maintain optimum soil fertility and to attain desired level of yield. Long-term fertilizer experiments provide a good illustration of the beneficial effect of combined use of inorganic fertilizer and organic manure in mitigating the deficiency of many secondary and micronutrients, which becomes more evident after a few years of continuous cropping by applying only NPK without any micronutrient fertilizer or organic manure. Development of alternative fertilizer material like enrichment of organic manures through minerals and their effect on crop productivity and soil fertility build-up has great potential which will give the benefits of applying an organic as well as inorganic fertilizer for increasing crop production and maintaining soil quality. The use of diverse organic sources of plant nutrients is becoming popular these days and compost has become important component in the integrated use of plant nutrients. However, the nutrient values of compost in terms of major nutrients are very low because of low concentration. The demerits of these materials could be overcome by introducing some low-grade minerals like RP. In India, total phosphate resource is estimated to be 260 Mt, and the recoverable phosphate reserves are of the order of 142 Mt. However, most of them are unsuitable for manufacturing of commercial P-fertilizers as well as for direct use as a source of P to crops in neutral to alkaline soil. The low-grade RP could be recycled through composting technology where the availability of P is expected to increase during composting. The product of enriched compost prepared using crop residues and low-grade RP along with phosphate solubilizing microorganism (PSM) *(Aspergillus awamori)* reveals that composting reduced the total carbon (C) but increased total nitrogen (N) content with the progress of composting period which reflected in the decrease of the C/N ratio and increase in total P content (Biswas and Narayanasamy, 2006). This technology revealed that crop residue could be converted into a value-added product in 90 days through composting technology using low-grade RP along with PSM. In order to improve the P content in the ordinary compost and to explore the possibility of use of low-grade RP as a source of P in place of costly P-fertilizers, a novel technology has been developed to prepare RP enriched compost using crop residue mixed with low-grade RP, waste mica and PSM (Biswas *et al.* 2009). The product of enriched compost was found to be very effective in crops like wheat, potato, maize, soybean, mungbean, *etc*. This product was also found very effective in terms of their residual effect to succeeding crop grown on residual fertility in a cropping sequence. Field evaluation revealed that 50% of recommended dose of NPK fertilizers could be substituted by product of enriched compost for crop production. The results clearly showed that enriched compost could be an alternative and cost-effective option to prepare a value-added product using agricultural wastes and low-grade minerals like RP and waste mica in place of costly chemical fertilizer for crop production and maintaining soil fertility (Biswas 2011; Meena and Biswas 2014).

Another novel product has been developed using organic acid loaded nano-clay polymer composite (NCPC) with RP and phosphate solubilizing bacteria (PSB, *Pseudomonas striata*) as P-fertilizer. Roy *et al*. (2015, 2018a, b) hypothesised that the novel product could solubilize P from low-grade RP through organic acids loaded NCPC and PSB which, in turn, release P slowly synchronizing crop demand for P. Results showed that RP along with organic acid (oxalic and citric acid) loaded NCPC and PSB inoculation performed significantly higher yield of wheat, P uptake and build-up of available P in soil compared to commercial DAP.

Controlled nutrient release is one of the best fertilizer management options to enhance nutrient recovery efficiency and minimize environmental pollution. The novel technology of controlled release fertilizers which harmonizes crop demand and release of P from fertilizers are promising to prevent the loss as well as improve the P use efficiency. Sarker *et al*. (2018) synthesized and assessed some polymer coated novel controlled release RP formulations to synchronize P release with crop demand and increasing P recovery by wheat. Polymer coated novel products were synthesized by partially acidulating RP with sulphuric and phosphoric acids followed by coating with polyvinyl alcohol and liquid paraffin @ 2 and 3% levels of coating. These products were characterized through X-ray diffraction, Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Phosphorus release pattern from novel coated fertilizers were monitored under controlled conditions in a laboratory incubation experiment at different moisture and temperature regimes. The products were also evaluated for their P supplying capacity to wheat in a greenhouse experiment. Results emanated from incubation study in a P-deficient Typic Haplustept revealed higher release of P at 20% moisture regime and 30 ^{o}C temperature. Phosphoric acid based coated products produced greater biomass yield than commercial diammonium phosphate and sulphuric acid formulated products. Product coated with polyvinyl alcohol @ 2% coating released P gradually that synchronized well with the plant P demand and resulted in greater biomass yield, P uptake and recovery by wheat than that of liquid paraffin and 3% level of coating. It can be concluded that novel technology of controlled release RP formulations using different coating agents could be exploited commercially as the alternative to water soluble P-fertilizers for enhancing P use efficiency.

Lack of information on P release from controlled release NP formulation and its impact on nutrient use indices has driven us to conduct another experiment where we developed NP formulations by reacting liquid ammonia and orthophosphoric acid in laboratory (Sarker *et al.* 2020). Resulting novel NP formulations were characterized by solubility fractions, microscopy, spectroscopy, and X-ray diffraction. After coating with poly(vinyl alcohol) (PVA) and liquid paraffin (LP) at 2 and 3 w/w% concentration, P release kinetics and temperature sensitivity (Q_{10}) of the formulations were compared with DAP at 20 and 30 °C temperature in a P-deficient soil for 120 h of incubation. Finally, nutrient use efficiency and relative efficiency indices were determined from a greenhouse experiment in potted soil to assess the effect of polymer-coated formulations and of DAP at two application rates in comparison with a non-P amended control. Laboratory synthesized NP formulations were alkaline in reaction, definite cubical to hexagonal crystalline structure with smooth surface generating peaks related to P and N in fingerprinting region of Fourier transform infrared spectroscopy. Polymer coating of NP formulations delayed the P release compared with DAP, while LP-coated formulations showing slower P release than PVA-based coatings. Despite LP-coated formulations showed greater temperature sensitivity (Q_{10}), the PVA-based formulation significantly increased yield and biomass accumulation of wheat, with concomitant increase in crop P uptake and P use efficiency. Both LP and PVA-coated formulations showed a significant residual P accumulation in post-harvest soils. The findings underline the potential of polymer coating technology for enhancing P use efficiencies, thereby reducing environmental P footprints.

In another study, Sarker *et al*. (2021a) prepared novel biodegradable clay-polymeric (starch/PVA) blended encapsulating films (CPSBs) from starch/PVA and assessed the economically feasible clay-fractioned bentonite for CPSB-encapsulated DAP production. The XRD, TEM and FTIR spectroscopy recognized the compatibility of bentonite with starch/PVA blend; several micropores in

CPSB surface was visible through SEM. Relative crystallinity index, density of CPSBs increased with increasing bentonite content (0–20 wt%); but, porosity, water absorption was decreased. Half-life of CPSB-10 was 37.4, 40.1 and 51.9 days with *Aspergillus awamori*, *Trichoderma viride* and uninoculated soil, respectively. Overall, greater bentonite content stabilizes the CPSB structure and CPSB-encapsulation reduced the N and P release from DAP.

The research was also conducted to formulate four novel oil-based formulations from different combinations of double-boiled linseed and mustard oils for coating DAP and to assess N and P release from them against uncoated DAP. Results revealed that novel oil-based formulation with 100 wt% linseed oil (Oil- 4 formulation) showed maximum variation in weight over the 30 days of curing; whereas, oil-based formulation containing 25 wt% linseed oil + 75 wt% mustard oil (Oil-1 formulation) had lowest variation in weight during curing (Sarker *et al.* 2021b). The N and P release pattern from oil-based formulations of coated DAP over 30 days in water medium with reference to uncoated DAP revealed that Oil-1 coated DAP formulation released lesser quantities of N and P than Oil-2 coated DAP; while 8% levels of coating material released lesser N and P than the 4% levels of coating. Compared to First-order kinetics model, the N and P release data were better fitted to Korsmeyer-Peppas model, which revealed that nutrient release from uncoated DAP followed Quasi-Fickian diffusion. Except 8%-Oil-2-DAP, all the oil-based formulations of coated DAP followed anomalous (Non-Fickian) diffusion. Thus, it may be concluded that double-boiled linseed and mustard oil-based formulations (Oil-1 formulation) of coated DAP could be an alternative option to produce cost effective controlled release fertilizers.

References

Biswas, D.R. (2011) Nutrient recycling potential of rock phosphate and waste mica enriched compost on crop productivity and changes in soil fertility under potato-soybean cropping sequence in an Inceptisol of Indo-Gangetic Plains of India. *Nutrient Cycling in Agroecosystems***89**, 15–30.

Biswas, D.R. andNarayanasamy, G. (2006) Rock phosphate enriched compost: An approach to improve low-grade Indian rock phosphate. *Bioresource Technology***97**, 2243–2251.

Biswas, D.R., Narayanasamy, G., Datta, S.C., Singh, G., Begum, Mamata, Maiti, D., Mishra, A. and Basak, B.B. (2009) Changes in nutrient status during preparation of enriched organomineral fertilizers using rice straw, low-grade rock phosphate, waste mica, and phosphate solubilizing microorganism. *Communications in Soil Science and Plant Analysis* **40**, 2285–2307.

Meena, M.D. and Biswas, D.R. (2014) Changes in biological properties in soil amended with rock phosphate and waste mica enriched compost using biological amendments and chemical fertilizers under wheat-soybean rotation. *Journal of Plant Nutrition* **37**, 2050–2073.

Roy, T., Biswas, D.R., Datta, S.C., Sarkar, A. and Biswas, S.S. (2018a) Citric acid loaded nano clay polymer composite for solubilizationof Indian rock phosphates: A step towards sustainable and phosphorus secure future. *Archives of Agronomy and Soil Science***64**, 1564-1581.

Roy, Trisha, Biswas, D.R., Datta, S.C. and Sarkar, Abhijit (2018b) Phosphorus release from rock phosphate as influenced by organic acid loaded nanoclay polymer composites in an Alfisol. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences***88**, 121-132.

Roy, Trisha, Biswas, D.R., Datta, S.C., Dwivedi, B.S., Lata, Bandyopadhyay, K.K., Sarkar, Abhijit, AgarwalB.K. and ShahiD.K. (2015) Solubilization of Purulia rock phosphate through organic acid loaded nanoclay polymer composite and phosphate solubilizing bacteria and its effectiveness as P-fertilizer to wheat. *Journal of the Indian Society of Soil Science* **63**, 327–338.

Sarkar, A., Biswas, D.R., Datta, S.C., Dwivedi, B.S., Bhattacharyya, R., Rajesh Kumar, Bandyopadhyay, K.K., Saha, M., Chawla, G., Saha, J.K. and Patra, A.K. (2021a) Preparation of novel biodegradable starch/poly(vinyl alcohol)/bentonite grafted polymeric films for fertilizer encapsulation. *Carbohydrate Polymers* 259, 117679, https://doi.org/10.1016/j.carbpol.2021.117679

Sarkar, A., Biswas, D.R., Datta, S.C., Dwivedi, B.S., Rajesh Kumar, Bandyopadhyay, K.K., Bhattacharyya, R., Saha, M., Biswas, S.S. and Patra, A.K. (2021b) Double-boiled linseed and mustard oil-based formulations to prepare oil-coated controlled release fertilizers *Indian Journal of Agricultural Sciences* **91,** 310–304.

Sarkar, A., Biswas, D.R., Datta, S.C., Roy, T., Biswas, S.S., Ghosh, A., Saha, M., Moharana, P.C., and Bhattacharyya, R. (2020) Synthesis of poly(vinyl alcohol) and liquid paraffin-based controlled release nitrogen-phosphorus formulations for improving phosphorus use efficiency in wheat. *Journal of Soil Science and Plant Nutrition***20**, 1770–1784.

Sarkar, A., Biswas, D.R., Datta, S.C., Roy, T., Moharana, P.C., Biswas, S.S. and Ghosh, A. (2018) Polymer coated novel controlled release rock phosphate formulations for improving phosphorus use efficiency by wheat in an Inceptisol. *Soil and Tillage Research***180**, 48–62.

Soil Organic Phosphorus and its Management for Sustainable Crop Production

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Phosphorus is an element that is widely distributed in nature and is one of the essential elements required by all living organisms. Phosphorus is an essential constituent of the energy transferring molecules ATP, ADP and AMP, and one of the genetic and information carrying molecules DNA and RNA of living organisms. Phosphorus is involved in different plant biochemical processes viz. energy transfer reactions, development of reproductive structures, protein synthesis, root growth and crop maturity. Phosphorus constitutes about 0.2 per cent (ranges 0.1-0.5 %) of a plant's dry weight, where it is a component of tissue molecules, such as nucleic acids, phospholipids and adenosine triphosphate. Plant roots absorb phosphorus from soil solution and it ranges from 0.001-0.1 ppm. In general, root absorb phosphorus in the form of orthophosphate ($H_2PO_4^-$ and HPO_4^{2}), but plant can absorb certain forms of organic phosphorus. Unlike nitrate and sulphate, phosphate is not reduced in plants but remains in its highest oxidized form.

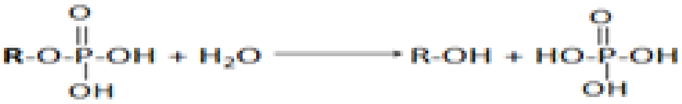
The total phosphorus in an average arable soil is approximately 0.1 per cent by weight, of which only an infinitesimal part is available to plant at any one time. Phosphorus is found in two forms in soil, namely organic and inorganic. Although total phosphorus is generally high, but 80 per cent of this phosphorus is immobile due to poor solubility, adsorption and precipitation and not available for uptake by the plant.

Phosphate rock is an important mineral source (apatite) with numerous uses and applications in agriculture. The fertilizer industry consumes about 90 per cent of world phosphate rock (or phosphorite) for phosphatic fertilizer production. About 80 per cent of world rock phosphate production is derived from deposits of sedimentary rock, 17 per cent is derived from igneous rocks and their weathering derivatives and the remaining comes from residual sedimentary and phosphatic fossil deposits.

In soil, approximately 15 to 80 per cent of total phosphorus is in organic forms, while the remaining is in inorganic forms. In an average soil, approximately 50 per cent of total phosphorus is organic. The principal organic phosphorus compounds present in soils are (a) inositol phosphate or phytin (i.e. Ca and Mg salts of phytic acid), (b) phospholipids (e.g. Lecithin), (c) nucleic acids (e.g. DNA and RNA), (d) phosphorylated sugars, (e) co-enzymes (e.g. GTP), and (f) phosphoproteins. Of these P containing organic compounds, the inositol phosphates, nucleic acids, phospholipids and molecules containing them are significant components of the soil organic P fraction. The inositol phosphates component are major constituents of the organic phosphorus fraction (10- 80 per cent of all the organic P), which are originated from microbial tissues. In most of the soil, nucleic acid-type compounds approximately contribute 1-5 per cent of the total organic P. The phospholipids contribute only 0.2- 2.5 per cent of the total organic P in soil. The specific amount of organic P in soils depends on a number of factors, including the type and nature of soil, vegetation, climate and management practices. Contribution of organic phosphorus to total phosphorus in Uttar Pradesh and Uttrarakhand, Punjab, Haryana, Himachal Pradesh, Rajasthan and Bihar are 36.2, 15.7, 31.2, 19.9, 45.6 and 21.44 per cent, respectively. Ratios of organic carbon to organic phosphorus of 100-300: 1 (generally 200:1) are common for mineral soils. If ratios are 300: 1 or wider (about 0.2 per cent P in organic matter), the microorganisms use most of the phosphorus, immobilizing it into their cell/tissues instead of releasing it for plant use.

Most of the organic phosphorus compounds are subject to rapid decomposition in soil and new products are synthesized by microorganisms. Mineralization is a process through which organic phosphorus in soil is converted into inorganic phosphorus with the help of soil microbes. Immobilzation on the other hand, is the reverse process of mineralization. During immobilization, inorganic phosphorus forms are converted back to organic forms and are absorbed into the living cells of soil microbes. Both mineralization and immobilization are biological and biochemical processes and these processes are influenced by soil moisture, temperature, pH, EC, organic C: organic P ratio, microbial population and diversity in soil as well as the contamination of toxic metals and non-metals and pesticides in soil. The microorganisms such as bacteria, fungi and actinomycetes (e.g. *Pseudomonas*, *Bacillus*, *Aspergillus*, *Penicillium*, *Arthrobacter*, *Streptomycetes*, *Rhizopus*, *Cunninghamella* etc.) mineralize the soil organic phosphorus compounds and release the inorganic phosphorus available for plant. The mineralization or decomposition processes are favoured by warm temperature, neutral soil pH and soil rich in organic phosphorus.

The enzymes that cleave phosphorus from the organic phosphorus compounds in soil are collectively called as *phosphatases*. These enzymes catalyze the following reaction. *Phosphatases* are hydrolase



$$\mathrm{R{-}O{-}\underset{OH}{\overset{O}{\overset{\|}{P}}}{-}OH + H_2O \longrightarrow R{-}OH + HO{-}\underset{OH}{\overset{O}{\overset{\|}{P}}}{-}OH}$$

Organic phosphorus compound
(R may have numerous structures
in organic-P compounds)

enzymes. The enzymes are classified as acid and alkaline *phosphatases* because they show optimum activities in acid and alkaline ranges, respectively. The acid *phosphatases* and alkaline *phosphatases* are the most important in soil organic P mineralization and plant nutrition. *Phosphatase*, an enzyme splitting off phosphates from complex organic molecules is exuded from plants. The *phosphatases* are also produced by bacteria and other organisms. The enzyme *phytase* liberates phosphate (H_3PO_4) from phytic acid/phytin with the accumulation of inositol.

The release of plant available forms of phosphorus from organic phosphorus in soil are depended on some important factors, viz. soil pH, soil micro-organisms population, soils moisture and soil temperature. Thus, amendment of liming materials in acid soil, straw mulching and addition of *phosphatase* enzyme releasing commercial micro-organisms in soil (such as *Pseudomonas*, *Bacillus*, *Trichoderma* etc.) are most efficient management practices for proper mineralization and releasing of plant available inorganic phosphorus in soil solution. Addition of fresh organic matters in soil, viz. poultry manure, vermicompost, phosphocompost containing enriched P should be the regular pactice to maintain the equilibrium between mineralization and immobilization of phosphorus in soil. Further, mycorrhizal fungi (VAM) have a dramatic effect on plants whose roots harbor these symboints. The symbiotic association of plant and the extensive hyphal network containing mycorrhiza allows for as extensive phosphate uptake in phosphorus deficient environment in soil. Thus, proper mycorrhizal culture incorporation is one of the suitable technology for the utilization of mineralized inorganic water soluble P from soil organic phosphorus by plant.

Keywords : Soil organic phosphorus (SOP), phosphatases, phytase, SOP management.

Opportunities for Mobilizing Residual phosphorus in agricultural soils

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Phosphorus (P) is an essential nutrient for plant growth and participating in various genetic and energy transformation processes in plants. It is one of the major limiting nutrients for plant growth in most agricultural soils worldwide. As the recovery of the applied P fertilizers is very less (10-20%) and rest more than 80% gets fixed in the soil in various forms including mineral phosphates, adsorbed P, organic P etc. Therefore, P is being used excessively in agricultural production systems from decades considering P fixation as a dominant and irreversible process. However, in recent studies it has been strongly evidenced for reversible sorption of added P and long-term use of residual soil P by plant roots. They reported that the sparingly soluble P pool in the soils may also be retrieved on depletion of P fertilization. Hence long-term recovery of P fertilization has to be the part of P use efficiency in different land use systems. Further, the traditional approach for P management in agriculture is no more viable option as the phosphate rock reserves are being depleted rapidly, prices of P fertilizers increasing inevitably, and pollution of aquifers and geopolitical issues. Further sufficient crop yields were achieved through technological intervention at reduced available P in soils of different agro-ecosystems. Therefore, various approaches need to be explored for mobilizing this important P reserve present in the soil system.

Approaches to utilize residual P in soils for plant nutrition

The soil solutions P can be replenished through desorption, solubilization and mineralization of residual P in soils using various technological interventions. The potential for the use of orthophosphates are generally higher in arable lands and esterified P in non-arable lands. The characterization and spatial mapping depicting the distribution of P species and their potential for bio-accessibility would also help in efficient utilization of residual P resources in different agricultural soils. Further, residual soil P can be exploited through combination of optimal P fertilization and management measures. The agronomic practices including cropping systems, crop rotation, use of cover crops, mulching, reduced tillage, retention of crop residues, planting techniques, irrigation techniques etc. significantly altered the P species and their accessibility for plant nutrition in the soil systems. Further the inclusion of P scavenging plant types in cropping systems enhancing the solubility of sparingly soluble P compounds for plant nutrition. Various amendments including organic manures, struvite, press mud/lime, sulphur containing amendments, bio-fertilizers, organic acids enriched wastewater etc. are being used in different condition for exploiting the residual P in

agricultural soils. Numerous microbial bio-fertilizers including species of phospho-bacteria, fungi, AMF inoculants, actinomycetes are being used for utilization of residual P in different agricultural soils. Enzyme related technologies including phosphatases and phytase through plant root secretion, microbial inoculants, and immobilized in manures/adsorbents mineralized the monoester phosphates present in the soil as residual P in different soils. Likewise, various organic acids are also being used in different forms for solubilization of orthophosphates present in the soils as residual P. Alteration of soil surface properties and rhizosphere chemistry using land management, root morphology, rhizo-depositions, wetting and drying of soils, use of oxidizing agents etc play important role in mobilization of residual P and improved the availability in different agricultural soils.

Keywords: Residual soil phosphorus, Agronomic management, Soil amendments, PSM, Soil Enzymes, Organic acids, Root and rhizo-depositions etc.

Soil Bioavailable-P and Stoichiometry Determine Microbial and Enzymatic Activity in Nutrient Management System

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Nutrient cycling ecosystem is mediated by microbial assemblages and their metabolic activities. Extracellular enzymes (enzymes outside of microbial cell membranes) are produced by the microbial assemblage to catalyze the degradation of organic matter in order to acquire organically bound nutrients. These mechanisms are linked with land use and management, nutrient availability and ecosystem metabolism which are complex, and likely mediated by microbial activity. Stichometry is the relationship between the relative quantities of substances (C, N, P, K etc.) taking part in a reaction or forming a compound, typically a ratio of whole integers. Further, enzymatic stoichiometry provides a biological perspective on the influence of anthropogenic disturbances to microbial C, N, P, and S acquisition resulting in an imbalance of nutrients being transported from these disturbances. Thus, ecological stoichiometric theory emphasizes the importance of the balance of biologically important elements for regulating an organism’s response to, regulation of their environment and finally improve productivity.

Microorganisms play an important role in mediating the availability of P to plants and fundamental to the soil phosphorus cycle. The microbial contribution to plant P nutrition and for enhancing P availability by manipulating specific microorganisms has therefore been of considerable interest over many decades. It is emphasized on P deficiency weathered and tropical soils throughout the globe. However, P fertilizer is indispensable for crop production in almost all soils although the efficiency of P use by plants from soil and fertilizer sources is often poor despite many soils containing a relatively large amount of total P that is only sparingly available to plants. The world’s high-quality sources of rock phosphate are limited and this itself justifies the need to develop agricultural systems that are more P efficient. Efficient utilization of microorganisms therefore, is an attractive proposition for developing a more sustainable agriculture to increase the availability of P in soil. The high-input production systems of the developed countries, and so to developing countries where access to mineral fertilizers is limited and thus, it is more relevant to the concept of microbial enhancement of P availability to plants. Gerretsen (1948) studied on P-solubilization under controlled conditions in pure cultures of soil bacteria could increase the P nutrition of plants through solubilization of precipitated forms of calcium (Ca)phosphates. Since this study, many researchers found that the microbially mediated P mobilization and characterization of different microorganisms have been effectively improved crop productivity (Hajra *et al*., 1992; Richardson, 2001; Khan *et al*., 20101).The benefits from soil micro flora in the crop production can be understood in two ways: (1) By promoting the activity of effective indigenous organisms, and (2) by introducing selected organisms that can influence their mutual development and exert combined effects on nutrient recycling and plant growth. The growth and activity of rhizosphere organisms are generally closely associated with their host plant development.

Low phosphorus concentration, coupled with low organic matter, is the major important constraint on the productivity almost all soils of tropical regions. The efficiency of use of applied P may be improved through an understanding of soil P dynamics in relation to management practices in a cropping system. Intensive use of long-term imbalanced chemical fertilizers application has been reported by several researchers to depress microbial activities and soil quality. However, crop rotation is universally accepted as beneficial to soil biodiversity and a necessary component of sustainable crop production, but the mechanism of rotation effect is often poorly understood.

AMF colonization can also be stimulated by the introduction of P-solubilizing organisms and rhizosphere organisms. At the same time plant roots possess phosphatase activity which may hydrolyze organic-P and release inorganic-P into the soil solution. Relationships between native soil microbe communities and AMF have received less attention. Organic phosphorus (Po) accounts for 20-80% of the total P in most mineral soils and contributes significantly to plant nutrition, as the release of inorganic P (Pi) from organic Po is primarily microbially mediated and the activity of soil microbes is closely related to chemically extractable labile organic Po (Hedley *et al*., 1982; Thien and Myers, 1992). Also a sequential phosphorus extraction procedure was used by many researchers to measure the change in the labile and stable forms of organic and inorganic P and to establish the relationship between soil biological activities and bioavailable P. However, a correlative index between rhizosphere biological activities and bioavailable P under field conditions have been rarely focussed (Manna *et al*., 2007). Further, there is a need to identify the best integrated nutrient management option for improving crop yield, reduce fertilizer P application and enhance microbial community in low or deficiency soils of tropical regions. Qualitative assay of rhizosphere microbial activity associated with AMF can give some insight how the rhizosphere environment is affected by fertilizer P along with FYM application rates on plant growth. We have investigated the possible influence of AMF colonization on the composition of native occurring organisms, rather than introduced organisms for transformation of bioavailable P.

Comprehensive information on C, N, P and S cycling enzymes, microbial elemental stoichiometry and soil functional diversity are scanty in organic vis-à-vis conventional systems across the globe. The most discriminant biological factor(s) and enzyme activity based quick, effective, sensitive index of soil quality have been studied under long-term organic farming system (Ghosh *et* *al*., 2019). In Vertisols of central India, microbial enzymatic activities, and harvest index were found significantly higher in organic plots. The soil microbial biomass, populations of bacteria, fungi and actinomycetes, as well as soil enzyme activities increased significantly in the compost-treated soils compared with a fertilizer treated hyperthermic, udic, haplaquept of China (Chang *et al*., 2007).This is especially true for N enrichment and the resulting increase in phosphatase activity (Sinsabaugh *et al*., 2009). Substrate quantity, quality and its microbial accessibility controls soil functional diversity thus the agro-ecosystems receiving organic C, N, P and S from different sources can affect microbial transformation of organic matter and functional diversity of microbial community in soil. Alteration or change in the soil system due to over-utilisation or other detrimental practices is responsible for higher microbial diversity. Soil organic carbon, arylsulfatase activity and available P to be the most effective discriminant factors among the conventional and organic nutrient management practices in Vertisols of India (Ghosh *et al*., 2019). Thus, the study will be useful for the researchers across the globe to find the most important discriminatory factors to specify management practices. Enzyme based soil quality index to be recommended for specific nutrient management practices. These indices or the discriminant factors could be utilized for supervising real-time soil quality quickly and effectively in diverse cropping systems.

***References*:**

Chang, E.H., Chung, R.S., Tsai, Y.H. (2007). Effect of different application rates of organic fertilizer on soil enzyme activity and microbial population. Soil Sci. Plant Nutr. 53,132–140.

Gerretsen F.C.(1948). The influence of microorganisms on the phosphate intake by the plant. Plant Soil 1: 51–81

Ghosh, A., A.B. Singh, R.V. Kumar, M.C. Manna, Ranjan Bhattacharyya, Mohammad Mahmudur Rahman, Poonam Sharma, P.S. Rajput and Sukanya Misra (2019).Soil enzymes and microbial elemental stoichiometry as bio-indicators of soil quality in diverse cropping systems and nutrient management practices of Indian Vertisols. Applied Soil Ecology.145:1-13

Hedley, M.J., and J.W.B. Stewart. (1982).A method to measure microbial phosphorus insoils. Soil Biol. Biochem. 14: 343-351.

Hajra, J.N., Manna, M.C. and Kole, S.C.(1992). Preparation and evaluation of enriched city compost in an alluvial soil. Indian J. agric. Sci. 62 (8): 540-544.

Manna, M. C., Subba Rao C.A. and Ganguly, T. K. (2007). Effect of Fertilizer Pand Farmyard Manure on Bioavailable P as Influenced by Rhizosphere Microbial Activities in Soybean-Wheat Rotation, Journal of Sustainable Agriculture, 29:3, 149-166.

Richardson A.E., Hadobas, P.A., Hayes, J.E., O’Hara, C.P. and Simpson R.J.(2001).Utilization of phosphorus by pasture plants supplied with myo-inositol hexaphosphate is enhanced by the presence of soil microorganisms. Plant Soil 229: 47–56

Thien, S.J., and R. Myers. (1992). Determination of bioavailable phosphorus in soil. SoilSci. Soc. Am J. 56: 814-818.

Sinsabaugh, R.L., Hill, B.H., Folstad Shah, J.J. (2009). Ecoenzymatic stoichiometry ofmicrobial organic matter acquisition in soil and sediment. Nature 462, 795–798.

Rock Phosphate-Enriched Organic Fertilizer and Microbial Inoculants: an Option to Increase Phosphorus Use Efficiency

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The available Phosphorus (P) content in soil is an important indicator for its cycling and transformation in soils. In general, plants acquire P from the soil solution, which is naturally replenished by different fixed or insoluble forms of P in the soil (Ghosal and Chakraborty 2012). The decreased availability of P in Indian soils including the soils of Bihar can be attributed to its affinity to get fixed by the formation of complex compounds in soils with dominant cations like calcium owing to the prevalent alkaline reaction (Beura *et al*. 2018). Soil test values for P are a more or less important indicator of P-cycling in soils, and can be considered to be an index for the response of crops to P fertilizers. Utilization efficiency of the crops for applied P generally ranges between 15 and 30%. The remaining amount contributes to the residual soil P build-up and is not lost easily except through erosion or runoff. Low availability of P in the soils of India is mostly the result of its affinity to get fixed (to an extent of 60%–70%) by calcium carbonate in alkaline and calcareous soils and by the hydroxides of iron and aluminum in soils of low pH (Meena and Biswas 2015). This decreased availability of P acts as a major constraint in attaining the maximum achievable yield for most of the crops including rice. Since most of the phosphatic fertilizers are imported from foreign countries it is an obvious burden on the foreign exchange reserves of the country (Beura *et al*. 2018). Moreover, they are too expensive for the farmers of our country who are resource poor with small landholdings. Also, it is important to consider that since the mineral resources are mostly finite and non-renewable, their optimal, uniform and economic use is indispensable to ensure sustainability for the future generation (Ditta *et al*. 2018). Locally deposited phosphates are available in India with some parts of them being unexploited while most of them being of low grade (Tarafdar 2013). Although rock phosphate has been found to have high P contents of nearly 28%–30%, it cannot be used directly as fertilizer owing to limited solubility and subsequent release of P that can be taken up by the plants (Reddy *et al*. 2002). The particle size, chemical properties and mineralogical nature of phosphate rocks in accordance with the important soil properties need to be considered to assess the suitability and efficacy of the phosphate rocks in releasing the phosphates in forms that are considerably plant available.

The solubility of P increases with an increase in organic matter content in soil and most of the P present in rock phosphate (RP) can be converted to plant-available forms by utilizing them in the preparation of composts due to the prevalent low pH environment during the process of composting which thus improving the nutritional value of the compost (Nishanth and Biswas 2008). Therefore, indigenous low-grade RP needs to be processed and RP Enriched composts (REC) are a possible alternative to more expensive soluble phosphate fertilizers in agricultural fields (Meena and Biswas 2014).

Since farmyard manure and conventionally prepared traditional composts contain very small amount of nutrients (generally), particularly P, compost enriched with rock phosphate can be effectively used as a potential alternative for sustaining the soil quality. Plants mostly take up P from the soil solution, which naturally replenished by various other pools P in the soil which are fixed or insoluble forms (Mengel and Kirkby 2001). Information about the different P pools is useful to assess the P available to plants and can be helpful to formulate proper nutrient management practices leading to an increase in P use-efficiency in the soil-plant system. Microbial biomass phosphorus (MBP) on the other hand plays an important part in maintaining the availability of P in soil and its role is more pronounced under highly weathered soils prone to P deficiency. Soil MBP has been found to mediate the transformations of P between inorganic and organic fractions and acts as an important source for the labile P in soil (Oberson *et al*. 2001). Generally, the MBP constitutes about 2%–10% of the total P content in soil, which is a much higher amount than the contribution of available P. The P flux through the turnover from microbial biomass is reportedly much higher than in its standing stock, based on previous estimations done in soils of agricultural fields, grasslands, and forests in both tropical and temperate regions of the world (Srivastava and Singh 1991).

P nutrition to the crops can be enhanced by the inclusion of microbial inoculants like plant-growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF). AMF have been widely reported to be able to improve the soil nutritional status along with the growth and development of plants. They also protect the plants against root pathogens and impart drought resistance to crops. AMF characteristically colonize the roots of host plants and facilitate the promotion the plant growth, which may be attributed to the increased uptake of nutrients particularly P thus improving the P nutrition to plants (Hirata *et al*. 1988, Smith and Read 2008). AMF are potentially capable of increasing the plant growth and can be alternatively used to substitute for the functions of some fertilizers mainly due to its role in enhancing nutrient uptake, particularly in low fertility soils (Cooper, 1986). Root colonization with the AMF significantly improves the nutrition of P in the plants grown on soils with majority of P in sparingly soluble forms (Shenoy and Kalagudi, 2005). AMF synthesize organic compounds like siderophores which help in the desorption of P into labile pools in soil. By producing organic acids, AMF can also solubilize the partially soluble or insoluble sources of P which are a part of the crystalline mineral structure in the soil. Organic exudates like citrates when released into the rhizosphere are effective in increasing the P availability to plants by mobilizing the less soluble Fe and Al phosphates or P fixed in form of insoluble Calcium phosphates.

PGPR in soil tend to secrete organic acids having low molecular weight (*esp*. Gluconic acid, fumaric acid and keto-gluconic acid, etc.) which dissolve phosphatic minerals (He *et al*., 2002) and bring the otherwise insoluble P into the labile pool which in turn contribute to the crop uptake. Certain P solubilizing bacteria like *Pseudomonas striata* can help in solubilizing the native P in soil for availability to the plants. Besides providing P for plant uptake, the phosphate solubilizing microbes also to some extent facilitate the plant growth by enhancing the efficiency of nitrogen fixation, improving the accessibility of other trace essential elements and by synthesizing important growth promoting compounds (Mittal *et al*., 2008).

The rock phosphate reserve and foreign exchange spent on importing raw materials for preparation of P fertilisers can be saved by preparation and use of compost enriched with rock phosphate.

Conclusion

Large scale import of P fertilizers acts as a major economic constraint in the agricultural scenario and widespread P deficiency in Indian soils makes P fertilizer management, an indispensable strategy to sustain crop production. Thus, the substitution of some parts of recommended dose with an organic alternative has immense potential in sustaining crop production and soil health. Results obtained from the above study could lead to a conclusion that the rock phosphate deposits of lower grade can be utilized for the preparation of enriched compost of higher nutritional quality. Conjunctive use of RPC and chemical fertilizers can be an effective P management strategy in P-deficient soils of India.

References

Beura, K., Singh, M., Pradhan, A.K., Rakshit, R. and Lal, M. (2018) Dissolution of dominant soil phosphorus fractions in phosphorus-responsive soils of Bihar, India: effects of Mycorrhiza and fertilizer levels. Communications in Soil Science and Plant Analysis 50(3), 287-294.

Meena, M. D. and Biswas, D. R. (2015) Effect of rock phosphate enriched compost and chemical fertilizers on microbial biomass phosphorus and phosphorus fractions. African Journal of Microbiology Research. 9(23), 1519-1526

Tarafdar, J.C. (2013) Phosphorus- A Bright Future Ahead ! Journal of Indian Society of Soil Science. 61, 29-37.

Reddy, M.S., Kumar, S. and Khosla, B. (2002) Biosolubilization of poorly soluble rock phosphates by Aspergillus tubingensis and Aspergillus niger. Bioresources Technology 84, 187-189.

Nishanth, D. and Biswas, D.R. (2008) Kinetics of phosphorus and potassium release from rock phosphate and waste mica enriched compost and their effect on yield and nutrient uptake by wheat (Triticum aestivum). Bioresources Technology 99,3342-3353.

Mengel, K. and Kirkby, E.A. (2001) Principles of Plant Nutrition. Netherlands. Kluwer Academic Publishers. 849 p.

Oberson, A. and Joner, E. (2004). Microbial turnover of phosphorus in soil. Organic Phosphorus in the Environment. 133-164.

Hirata, H., Masunaga, T. and Koiwa H. (1988) Response of chickpea grown on andosoil to vesicular-arbuscular mycorrhizal infection in relation to the level of phosphorus application. Soil Science and Plant Nutrition 34, 441–449.

Smith, S.E.and Read, D.J. (2008) Mycorrhizal symbiosis. Academic Press, London,UK.

Shenoy, V.V. and Kalagudi, G.M. (2005) Enhancing plant phosphorus use efficiency for sustainable cropping. Biotechnology Advances 23, 501–513.

He, Z.L., Bian, W. and Zhu, J. (2002) Screening and identification of microorganisms capable of utilizing phosphate adsorbed by goethite. Communication in Soil Science and Plant Analysis 33,647-663.

Mittal, V., Singh, O., Nayyar, H., Kaur J. and Tewari R. (2008) Stimulatory effect of phosphate-solubilizing fungal strains (Aspergillus awamori and Penicillium citrinum) on the yield of chickpea (Cicer arietinum L. cv. GPF2). Soil Biology and Biochemistry 40, 718–727.

Potential K Supplying Capacity of a Soil -A Mechanistic Approach

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Potential K supplying capacity of a soil is not same as available K extracted by 1N ammonium acetate, but a fraction of it and sometimes a part of non-exchangeable K along with it depending upon the level of exchangeable K, type of crop plant, K transmission and release characteristics of the soil. K transmission factors are tortuosity or impedance factor depending on moisture content, water filled porosity and buffering capacity of the soil. K release characteristics of the soil depend on the nature of K bearing minerals i.e., muscovite or biotite as evident from the K release threshold level of the soil.

The plant factors are K absorption rate of root per unit surface area, total root surface area as reflected in root length density and it's rate of growth with time, distribution of root at different depths of soil and transpiration rate of the plant.

A simulation model of K uptake in cylindrical coordinates can be constructed taking all the factors in consideration which will predict potential K supplying capacity of a soil for different crops at different moisture levels below saturation level. At saturation level anaerobiosis sets in and K is excluded from plant root, because K uptake is an energy dependent process requiring oxygen uptake.

This model will also help in determining K fertiliser dose to be applied for different soils, crops and moisture availability.

Crop Productivity and Quality via-a-vis Sulphur Management Strategies in Indian Agriculture

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Sulphur is the fourth most important nutrient after nitrogen, phosphorus and zinc for Indian agriculture. Sulphur is best known for its role in the synthesis of proteins, oils, vitamins and flavoured compounds in plants. Three amino acids viz. Methionine (21%S), Cysteine (26%S), and Cystine (27%S) contain S which are the building blocks of proteins. About 90% of sulphur is present in these amino acids. Sulphur is also involved in the formation of chlorophyll, glucosides and glucosinolates (mustard oils), activation of enzymes and sulphydryl (SH-) linkages that are the source of pungency in onion, oils, etc. Sulphur is also a constituent of vitamins biotine and thiamine (B1) and also of iron sulphur proteins called ferrodoxins. Sulphur is associated with the production of crops of superior nutritional and market quality (Tandon 1991). Sulphur plays an important role in physiology and protection of plants against environmental stresses and pests through its anti-oxidative protective functions (Zenda *et al.* 2021). Adequate sulphur is therefore very much crucial for oil seeds, pulses and cereal crops. In spite of these numerous sulphur roles being well acknowledged, agriculture has paid scant regard for sulphur nutrition, until only recently. Sulphur deficiencies have been reported from over 70 countries worldwide including India. Sulphur deficiencies in India are widespread and scattered throughout 120 districts out of 400 districts (Tandon 1991). Deficiency of sulphur in Indian soils is on increase due to intensification of agriculture with high yielding varieties and multiple cropping coupled with the use of high analysis sulphur free fertilizers along with the restricted or no use of organic manures have accrued in depletion of the soil sulphur reserve. Crops generally absorb sulphur and phosphorus in similar amounts. On average, the sulphur absorbed per tonne of grain production is 3-4 kilograms in cereals, 8 kilograms in pulses, and 12 kilograms in oilseeds (Tandon 1991). Soils, which are deficient in sulphur, cannot on their own provide adequate sulphur to meet crop demand resulting in sulphur deficient crops and sub-optimal yields.

Sulphur in soil occurs both in organic and inorganic forms. Depending upon the soil and climatic conditions, contents of these forms are expected to vary from one place to other. In view of this, the knowledge about the forms of occurrence of sulphur is absolutely necessary to have a watch on its supply capacity in soils. Intensive cropping without sulphur application can deplete those soils also, which are presently adequate in sulphur. The knowledge of sulphur status throughout root zone is essential for improving sulphur nutrition of crops. Several soil factors influence the availability of sulphur and hence the status of different forms of sulphur in soils varies widely with soil type (Ghosh *et al.* 1991, Tandon 1991). Distribution of sulphur forms and their interrelationship with some important soil properties decide the sulphur supplying power of soil by influencing its release and dynamics in soil. Plant available sulphate can be extracted by calcium chloride or calcium orthophosphate solution and 10-13 mg SO_4-S kg^{-1} surface soil was found to be crucial for the optimum plant growth. Sub-soil fertility also needs due consideration to have better prediction of sulphur supply in growing plants (Chattopaddhyay and Ghosh 2006, Chattopaddhyay and Ghosh 2009, Patra *et al.* 2012).

Sulphate is the primary source of sulphur taken up by most of the crops. Soil solution sulphate level determines the amount of sulphur accessible to a plant. The source of this solution sulphate is either from organic matter via the microbial pool or directly from animal residues, atmospheric inputs or fertilizer. Reduced forms of sulphur must first be oxidized in soils to the sulphate form before crops can use them. The oxidation of elemental sulphur (S^0), sulphide sulphur ($S^=$) and other inorganic sulphur compounds occurring in soils is thought to be biochemical in nature. The rate of oxidation in soils varies depending on the soil environmental conditions, characteristics of the sulphur sources and the microbial population in soils. The oxidation and reduction of inorganic sulphur compounds are of great importance to growing plants. In the first place, these reactions determine to considerable extent the quantity of sulphate present in soils at any one time. Since this is the form taken up by plants, the nutrient significance of sulphur oxidation and reduction is obvious. Second, the state of sulphur oxidation determines to a marked degree of the acidity of a soil. Comparative oxidation of sulphur compounds viz. elemental sulphur and pyrites under limed and non-limed conditions have the special significance on sulphur nutrition to crops (Patra *et al.* 2012).

Beneficial effect of sulfur application on increasing yield of several oilseed, cereals, pulses and cash crops has been reported in sulfur deficient soils by several workers (Das and Ghosh 2012, Pati *et al.* 2011, Chattopaddhyay and Ghosh 2012, Patra *et al.* 2013, Tandon 1991). The performance of various sulfur sources like gypsum (14–16% S), phosphogypsum (14–16% S), ammonium sulfate (24% S), single super phosphate (24% S), pyrites (22–24%) and elemental sulfur (85–100% S) have been reviewed by Sakal and Singh (1997). Gypsum, the most widely studied sulfur material has been reported to be an efficient source for wheat, groundnut, rapeseed and mustard in soils. Only recently, magnesium sulfate has been included in the Fertilizer Control Order and given due recognition as a fertilizer. Magnesium sulfate (MgSO4. 7H2O), which is produced and used most commonly in India, is also called Epsom salt, containing 16% MgO and 13% S. Generally, it is selected for application in situations where Mg application also is required, as is case with several horticultural, plantation and field crops in Mg-deficient soils (Tandon, 1995, Dash and Ghosh 2012).

The increasing demand for and escalating cost of sulphur fertilizers during the last decade have stimulated increased interest in the development of technology for more efficient S fertilizer use. Adsorption-desorption characteristics are useful for describing, studying and managing the sulphur status of soils. The adsorption process, which refers to surface S accumulation on soil components, may, in some cases, be accompanied by penetration of the adsorbed S by diffusion into the adsorbent body, leading to further adsorption of the adsorbed species. The general term sorption sometimes used to denote both of these processes taking place simultaneously. Both adsorption and desorption studies have indicated the fertility status of soil, particularly under long-term fertilizer trials dealing with both organic and inorganic materials. The nature of sulphate adsorption in a system can be known by fitting adsorption data to isotherm equations. The main motivations for describing adsorption curves are: (1) To identify the soil constituents involved in adsorption, (2) To predict the amount of fertilizer needs of soil to meet the demand of plant uptake for an optimum yield, and (3) To study the nature of the adsorption processes to learn more about the mechanism of the process. A variety of isotherm shapes are possible, depending upon the affinity of the adsorbent for the adsorbate. In general, for soil sulphur and phosphorus, Langmuir and Freundlich adsorption equations have been used extensively by different workers. Several factors affect the sulphate sorption by soil. Among these, pH and presence of complexing anions, clay content, extractable Fe and Al, soil horizon type, organic carbon, $CaCO_3$ content and native extractable sulphate are the most important. The process of desorption refers to the reversible release of adsorbed sulphur into the soil solution phase. Desorption of once sorbed sulphur from soil and clays often has been shown to be irreversible leading to a large hysteresis effect**.** Thus, the concentration of sulphate in soil solution as predicted by sulphate sorption – desorption curves provides a valuable information on sulphur availability to crop plants. It indicates the immediate concentration at which sulphate should be available to plants and concentration of sulphate in water that drains from a particular horizon. Sorption of sulphate can result in the release of OH^- ions to the bulk soil solution and can increase the cation exchange capacity. Information on the sulphate sorption– desorption characteristics has special bearing in soils.

In the acute shortage of edible oils and pulses for human diet in the country, sulphur can play key role in augmenting the production of oilseeds and pulses. Elemental S–based products are the most concentrated source of S (85 – 100%S). Upon addition to the soil, elemental S has to be oxidized to yield the SO_4 from that can be absorbed by plants. This oxidation is accomplished by soil bacteria. The rate of oxidation depends upon the particle size of S, its degree of contact with soil, temperature, moisture, and aeration. In order to allow adequate time for transformation, it is applied 3 – 4 weeks ahead of planting the crop.

Since India is a net importer of sulphur for manufacturing some of the important nitrogenous, phosphatic and potassic fertilisers. Therefore, alternative sulphur supply strategies must emphasize the use of indigenous sources of sulphur, the most dependable and cheaper such as pyrites and phosphogypsum. Pyrites (FeS2) is a mineral containing iron and sulphur (22 – 24%). Extensive deposits of sedimentary iron pyrites exist near Amjhore in Bihar, India. In contrast to elemental S which oxidizes in the soil to produce sulphuric acid mainly through *Thiobacillus thiooxidans* bacteria, oxidation of pyrite in soil initially is brought about primarily through chemical action and microbial agents like *Thiobacillus ferroxidans* may be playing a minor role. Pyrites, a slow-release source of S is likely to prove a relatively better source of S in mitigating the increasing deficiency of S in intensively cropped soils. On the other hand, phosphogypsum (16% S, 21% Ca and 0.2 – 1.2% P2O5) is the byproduct gypsum obtained during the manufacture of wet process phosphoric acid. Phosphogypsum can thus serve as the source of sulphur and calcium for plant growth like mineral gypsum. Less than 10% of the phosphogypsum is being used for agricultural purposes. Only recently, magnesium sulphate has been included in the Fertiliser Control Order and given due recognition as a fertilizer. Magnesium sulphate, which is produced and used most commonly in India, is the Epsom salt, MgSO4. 7H2O containing 16% MgO and 13% S. Generally, it is selected for application in situations where Mg application also is required, as is case with several horticultural, plantation and field crops in Mg-deficient soils. Studies on these indigenous sources of sulphur vis-a-vis single superphosphate and elemental sulphur on yield and quality characters of cereals, oilseeds and pulses hopefully could contribute to future sulphur management strategies in soils.

Additionally, in light of the emerging problems of soil fertility exhaustion and climate change-exacerbated environmental stresses, sulphur assumes special importance in crop production, particularly under intensively cropped areas. I intend to highlight, in addition to its plant biological and metabolism functions, how sulphur can significantly enhance crop productivity and quality, as well as acclimation to abiotic stresses. The aim of this deliberation is to arouse scientific interests particularly of young scientists in crop sulphur research by providing priorities for future pursuance, including betterment of our understanding of the molecular processes and dynamics of sulphur availability and utilization in plants, investigate the role of soil rhizosphere microbes in sulphur transformations, enhancing plant growth and diagnosis for nutrient deficiencies, and matching site-specific crop sulphur demands with fertilizer amendments in order to reduce nutrient use inefficiencies in both crop and livestock production systems. This will facilitate the proper utilization of sulphur in crop production and eventually enhance sustainable and environment friendly food production.

References

Chattopaddhyay S and Ghosh GK. 2006.Sulphur status in some red and lateritic soils of Birbhum district of West Bengal. *Indian Journal ofFertilisers*, 2(2),35-38.

Chattopaddhyay S and Ghosh GK. 2009. Vertical distribution of forms of sulphur in some profiles of Birbhum district of West Bengal. *J. Interacad.* 13(1):28-35.

ChattopaddhyaySomnath and GhoshGoutam Kumar .2012. Response of Rapeseed *(Brassica juncea* L.) to various Sources and Levels of Sulphur in Red and Lateritic Soils of West Bengal, India.*International Journal of Plant, Animal and Environmental Sciences* 2(4): 50 -59.

Dash N R and Ghosh G K .2012. Efficacy of Gypsum and Magnesium Sulphate as Sources of Sulphur to Rapeseed in Lateritic Soils. *Journal of Plant Nutrition,* ***35*** *(14): 2156 - 2166.*

Ghosh GK, Singh TA, Srivastava PC & Ghosh D. 1991. Sulphur fractions in soils of North-West Uttar Pradesh – I. Relationship with soil properties. J.Res. BAU, 3(1): 17-24.

Ghosh, G K and Dash N R (2012) . Sulphate Sorption–Desorption Characteristics of Lateritic Soils Of West Bengal, India.*International Journal of Plant, Animal and Environmental Sciences* 2(1): 167-276.

Patra P, Mondal S and Ghosh GK. 2012. Distribution of Sulphur Fracttions in Surface and Sub-surfaace Soils of Red and Lateritic Soils of West Bengal. Indian Agriculturists 56 (1&2):1-7**.**

Pati BK, Patra P, Ghosh GK., Mondal S, Malik GC. and Biswas PK. 2011.Efficacy of phosphogypsum and magnesium sulphate as sources of sulphur to sesame (Sesamum indicum L.) in red and lateritic soils of West Bengal. *Journal of Crop and Weed* 7(1):133-135.

PatraParitosh, MondalSuchhanda and GhoshGoutam Kumar . 2012**.** Status of available Sulphur In Surface and Sub-Surface Soils of Red and Lateritic Soils of West Bengal.*International Journal of Plant, Animal and Environmental Sciences* 2(2): 276 - 281.

PatraP, PatiBK , GhoshGK, MondalS, MalikGC and BiswasPK .2012. Oxidation pattern of elemental sulphur as affected by levels of sulphur, organic matter and liming in a typical lateritic soil of West Bengal.*Journal of Crop and Weed* 8(2): 29 -31.

Patra P, Pati BK, Ghosh GK, Mura SS and Saha A .2013. Effect of Biofertilizers and Sulphur on growth, Yield and oil content of hybrid sunflower (*Helianthus annus* L.) in a typical lateritic soil. 2:603 doi:10.4172 / scientificreports.603

Sakal R and Singh AP. 1997. Sulphur in Balanced Fertilisation in Eastern India. In: Proc. of TSI / FAI / IFA Symposium on Sulphur in Balanced Fertilisation, SI-2 / 1-6.

Tandon HLS. 1991. Sulphur Research and Agril. Production in India, 3rd edition. The Sulphur Institute, Washington D.C. USA, Pp. 140 + viii.

Tandon, HLS. 1995. *Sulfur Fertilizers for Indian Agriculture –- A Guidebook*. New Dehli: Fertilizer Development and Consultation Organization.

Zenda T, Liu S, Dong A, Duan H .2021. Revisiting Sulphur—The Once Neglected Nutrient: It’s Roles in Plant Growth, Metabolism, Stress Tolerance and Crop Production. *Agriculture*, *11*, 626. https:// doi.org/10.3390/agriculture11070626

Diagnosis of Nutrient Deficiencies through Artificial Intelligence

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Introduction

In the era of modernization and the developing world, technologies play a vital role in almost all sectors. Human survival greatly depends on Agriculture but we are still using the traditional methods in the agricultural practices (Yogesh *et al.,* 2019). Plants require essential nutrients for normal functioning and growth. Nutrient is a vital factor that strongly determines the growth rate, productivity and fertilization (Zubler and Yoon, 2020). Deficiencies in any essential nutrient significantly affect and cause a severe loss in agriculture (Noinongyao*et al.,* 2018). Identifying nutrient deficiency in crops is still difficult for farmers. We are still using ancient methods to identify nutrient deficiency in crops which consume more time, labour and cost.

Importance of nutrient deficiency detection

The detection of nutrient deficiencies refers to the task of recognizing nutrient limitations of crops, such as nitrogen (N), phosphorous (P) and potassium (K) deficiency (Yi *et al.,* 2020). Reliable diagnosis of the nutritional status of crops is an essential part of farm management. Both excess and deficiency of nutrients can cause severe damage and yield loss. If identified wrongly, product yield, money and time will tend to lose. Hence, accurate determination of the nutritional status not only prevents yield losses but also waste of financial resources is avoided and environmental impacts are reduced (Rao, 2019).

In general, nutrient deficiencies are identified through agricultural laboratories and experienced researchers/farmers. The predictions on nutrient deficiencies manually may go wrong due to several factors. The nutrient deficiency in crops can appear in their leaves, stem, flowers, fruits, etc. (Xu *et al.,* 2011). These nutrients are divided into micronutrients and macronutrients. The deficiency in these nutrients causes many disorders in the crops. This will ultimately affect the yield rate. Generally, the nutrient deficiencies are identified in the leaves of the crop plants by the symptoms such as yellowing of leaves, reduction in leaf size, distorted edges, necrosis, etc. The farmer or the researcher needs to uproot the entire plant and test the defected plant in the corresponding laboratory to identify the appropriate nutrient deficiencies.

Artificial intelligence (AI)

One of the most recent tools for nutrient deficiency detection is by using artificial intelligence technologies. Spectral sensing has become a versatile tool for evaluating nutrient status and determining fertilizer demand (Reckleben, 2014). The term “Artificial Intelligence” was coined by American scientist John McCarthy in 1956. Artificial intelligence (AI) is branch of computer science by which intelligent machines are created which can behave like a human, think like humans, and able to make decisions on their own. According to John McCarthy, “Every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it. The present write-up is an attempt to find how to make machines use language, form abstractions and concepts, solve kinds of problems reserved for humans and improve themselves”.

Artificial intelligence refers to the simulation of human intelligence in machines that are programmed to think like humans and mimic their actions. The term may also be applied to any machine that exhibits traits associated with a human mind such as learning and problem solving. Artificial intelligence makes it possible for machines to learn from experience, adjust to new inputs and perform human like tasks. These tasks rely heavily on deep learning algorithms. Using these technologies, computers can be trained to accomplish scientific tasks by processing large amounts of data and recognizing patterns in the data. Artificial intelligence is a broad branch of computer science which mainly can be divided into two branches: symbolic learning and machine learning. Symbolic learning consists of sub-branches like robotics and computer vision and machine learning consists of sub-branch deep learning which can be further divided into artificial neural network (ANN), convolutional neural network (CNN) and recurrent neural network (RNN) which mainly performs the work of numerical data recognition, object recognition and speech recognition and natural language processing respectively.

SPAD chlorophyll meter

Nitrogen (N) is one of the essential elements that affect crop productivity (Bachick*et al.*, 2017). It is needed in the large quantity due to its role in stabilizing and enhancing crop growth and yield production (Saberioon*et al.*, 2013). SPAD chlorophyll meter is a portable device which allows instantaneous measurement of chlorophyll content or greenness of a leaf which is proportional to the N-content of the leaf (Gholizadeh*et al.*, 2011). It has a sensor which emits two frequencies of lights- the red light (650 nm) and the infrared light (940 nm). The chlorophyll absorbs red light and not infrared light. The signal is received by a microprocessor and calculates the SPAD value as the ratio of the two absorption values.

Working of a SPAD meter

1. Turn on the SPAD meter.
2. Press the handle bar without any leaf to calibrate it. Once the meter reads blank, it is ready for use.
3. Choose a nutrient deficient leaf and place it in the space of the handle bar. Press the handle bar and record the reading. Usually, three subsequent values are taken per leaf.
4. Click on the average button to get the average values.
5. Click on the clear all data button and the device is ready for the next sample.

The ideal time to take the data is 7 am to 9 am to minimize light intensity on chloroplast.

Plate 1: SPAD chlorophyll meter

Terrestrial laser scanning technology (TLS)

It is mainly used for tree condition assessment especially in the horticultural orchards (Escola *et al.,* 2015). A laser scanner can quickly and accurately measure a 3-d environment by measuring the distance and angles to the target object. The laser scanner is carried on a tripod on ground at around 1.5 m. When a laser beam of the IR wavelength hit the object, it will reflect back to the sensor (Calders*et al.,* 2020). The time difference between the emitting beams and the receiving beams will be used to measure the distance between the laser scanner and the object of interest. Once scanning is done, the scanned data is transferred to the working computer, processed and passed to software such a “could compare”. The data is then fed to CNN as input which helps us to know the pattern of the patches on the tree.

Plate 2: Terrestrial laser scanner

Drone technology

A drone is a device fitted with sensors, camera and GPS to collect information of the crop. Drones are of great importance as they can aid farmers to deal with their everyday tasks in a more advanced way (Raeva*et al.,* 2018). It is allowed to fly over the field and detect and track the object of interest by associating a univocal ID to each crop. Pictures of every single crop are taken. The sensors are connected to the transmitter which transmits the information to the receiver i.e., computer. These data are then used to train the deep learning model and later, this model can detect the crops that it has never seen before and generate the image map.

Plate 3: Drone

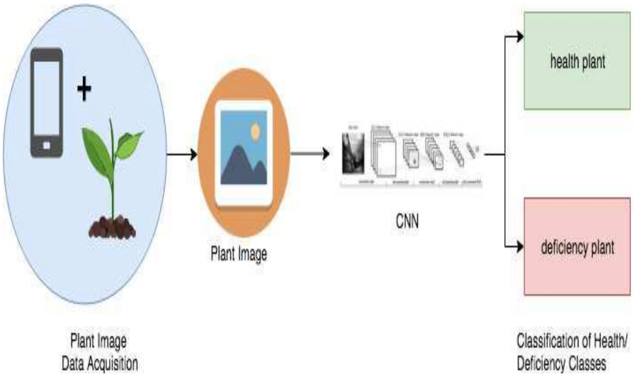

Figure 1: Identification of nutrient deficient plants through image acquisition and fed to CNN

RGB imagery sensor

An investigation was carried out by Yuzhu*et al.*, (2011) at Vegetable Teaching Base of Jilin Agricultural University, China on nitrogen determination in pepper (*Capsicum frutescens* L.) plants cv. Jijiao No. 8 by color image analysis (RGB).

Table 1: Treatments of nitrogen

Sl. No.	Total N application (kg/hm²)	Base fertilizer (kg/hm²)	Topdressing at flowering stage (kg/hm²)	Topdressing at fruiting stage (kg/hm²)
Control	0	0	0	0
1	75	30	20	25
2	150	60	40	50
3	225	90	60	75
4	300	120	80	100
5	375	150	100	125

The Canon G3 digital camera was used to capture coloured images. Size of the images was 1024*786 pixels. Coloured images were acquired with digital camera: red, green and blue bands. The collected images were stored in the PC, processed and analysed by Adobe Photoshop 7.0. Regression analysis was performed to see the relationship between nitrogen concentration in soil and various standard RGB indexes of pepper canopy surface.

Table 2: The relationships between standard RGB indexes of pepper canopy and nitrogen concentration in soil

RGB index	G	G/R	G/B	G/(R+G+B)	B/(R+G+B)
R^2	0.210*	0.624**	0.657**	**0.763****	0.655**

* Significant at $p<0.05$; ** Significant at $p<0.01$

The coefficient of regression equation of G/(R+G+B) ratio was found to be highest. Hence, G/(R+G+B) ratio was a favorable index to express pepper N status. Following indices of pepper N status were considered: Inorganic nitrogen in soil, total nitrogen of plant, nitrate concentration of leafstalk and SPAD readings.

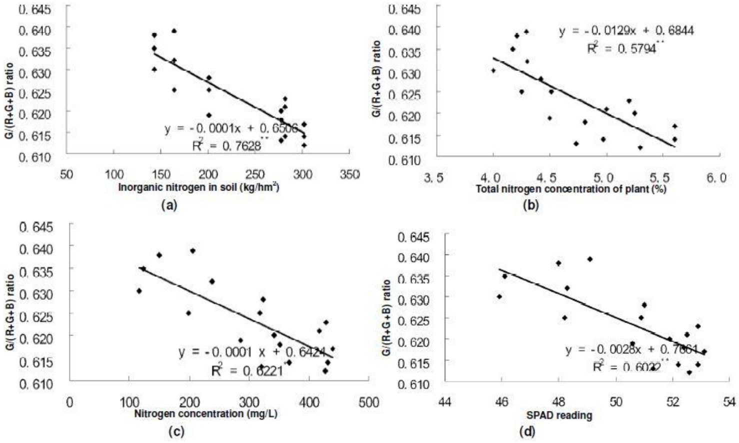

Figure 2: The correlation between G/(R+G+B) ratio of pepper surface by color image analysis and inorganic nitrogen concentration in soil, total nitrogen concentration of plant, nitrate concentration of leafstalk and SPAD reading. ($p<0.01$)

Significant negative correlation between G/(R+B+G) ratio and all the indices of pepper N status were observed. Hence, *G/(R+G+B)* ratio of coverage image can be used to express the pepper N status. It is a favourable method to assess pepper nitrogen status with RGB imagery.

Computer vision technology

Computer vision is a field of artificial intelligence that trains computers to interpret and understand the visual world i.e., the computer sees the image from camera and deep learning model. As soon as the computer sees the image, it analyses the image and matches with its stored data. With the development of computer and technology progress, computer vision provides a new solution for the research of healthy plant growth (Zhao *et al.*, 2007).

Machine learning based nutrient deficiency detection in crops

The machine learning usage has grown in recent years to meet the growing demand for fast and accurate methods in monitoring nutrient status (Patricio and Rieder, 2018). The extracted features from the image are compared with the trained and already available dataset and identified whether it is a healthy or nutrient deficient plant. A study was conducted at Department of Electronics and Communication Engineering, Agni College of Technology, Thalambur, Chennai. The captured image was processed by CNN which compares the input images with already existing images of the dataset. When matched, it displayed the nutrient deficiency in terms of percentage. The flow diagram of the system is as follows:

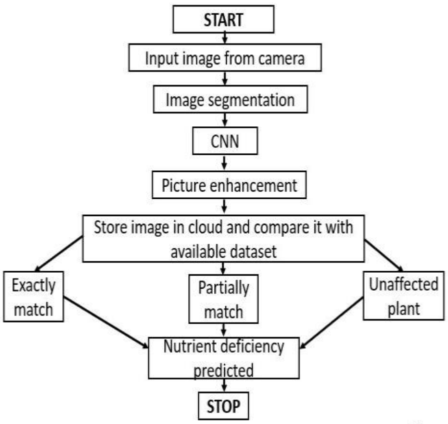

Figure 3: Flow diagram of the system

Chlorophyll fluorescence technique

Aleksandrov (2019) also tried to identify nutrient deficiency in bean (cv. Cheren Starozagorski) plants by prompt chlorophyll fluorescence measurements and Artificial Neural Networks at Institute of Plant Physiology and Genetics, Bulgarian Academy of Science. Chlorophyll fluorescence is the fluorescence or radiation emitted by the chlorophyll (Gorbe and Calatayud, 2012). Bean plants were grown on a complete nutrient solution (control) and compared with those grown in solutions which lacked one of these elements- N, P, K, Ca and Fe. Photosynthetic activity was estimated by analysis of chlorophyll fluorescence using JIP-test approach. Every plant was kept in dark for at least 30 mins before analysis. The fluorescence transients obtained were fed as input data in ANN. The ANN was trained to recognize deficiency of N, P, K, Ca and Fe in bean plants.

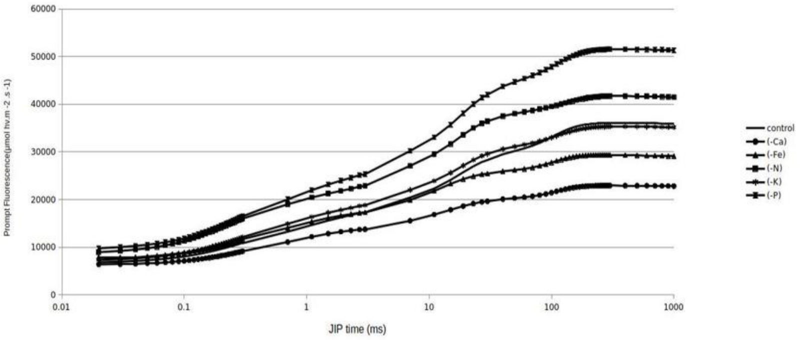

Figure 4: Fluorescence curves obtained in Bean leaf, control and grown in N, P, K, Ca and Fe deficiencies

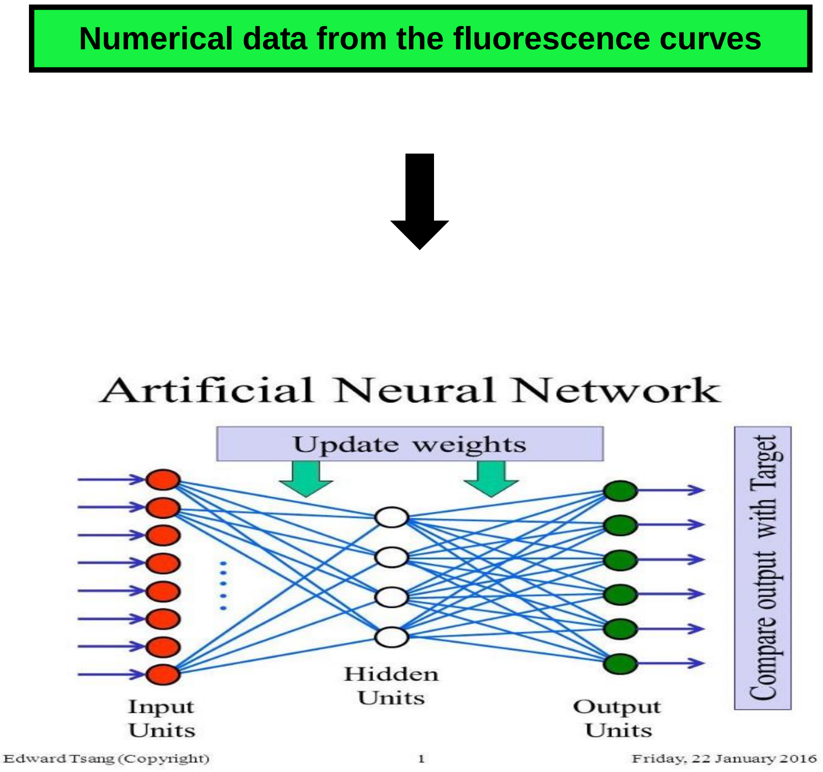

Figure 5: Data from the Fluorescence curves fed to ANN

Support vector machine algorithm

It is a machine learning algorithm which classifies the images as a point in space and the coordinates of the point are called features. It is a classifier which classifies the raw data into separate classes through feature extraction by generating a hyperplane. An experiment performed by Asraf*et al.*, (2012) in Malaysia with oil palm crop where deficiencies of nitrogen, potassium and magnesium were studied via SVM classifier. Magnesium possessed features with fewer fluctuations than potassium whereas nitrogen had distinguishing pattern compared to both magnesium and potassium.

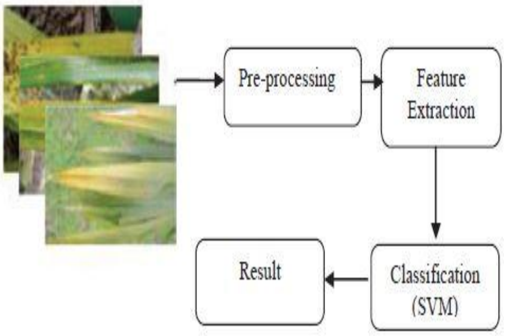

Figure 6: Methodology flowchart

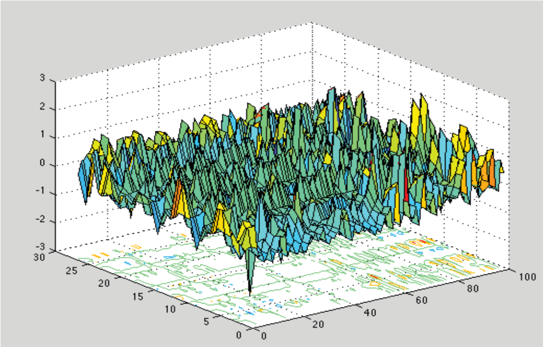

Figure 7: Graphical representation of feature extraction of potassium

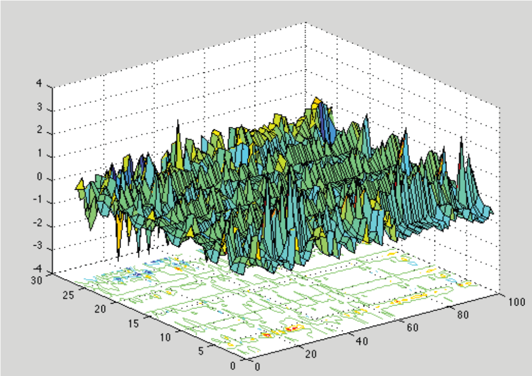

Figure 8: Graphical representation of feature extraction of magnesium

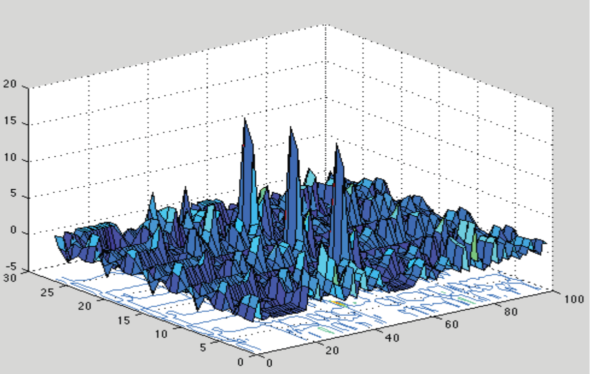

Figure 9: Graphical representation of feature extraction of nitrogen

Limitations

- In many cases farmers and researchers do not have enough knowledge about the machine learning techniques they are applying.
- As a result, the experiment is not always appropriate, causing many proposed methods to be suboptimal.
- To avoid this kind of error, someone with experience in machine learning should always be involved in the experiments.

Conclusion

- Through artificial intelligence, early prediction of nutrient deficiencies is possible.

- Visual alterations in the plant's color and morphology can be detected using the appropriate technology.
- Classification problem can be suitably tackled, as long as the experiments have been adequately designed and the data available is representative enough.
- But, building a dataset for model calibration and training of all possible classes of symptom is a tedious task, especially in the case of crop nutrient disorders.
- AI is the game changing tool as per as the modern agriculture is concerned.

References

Aleksandrov, V. (2019). Identification of nutrient deficiency in bean plants by prompt chlorophyll fluorescence measurements and Artificial Neural Networks. doi: 10.48550/arXiv.1906.03312.

Asraf, H.M., Nooritawati, M.T., and Rizam, M.S.B.S. (2012). A comparative study in kernel-based support vector machine of oil palm leaves nutrient disease. *Proced. Engg.,* 41: 1353-1359.

Bachick, N.A., Hashim, N., Wayayok, A., Che Man, H., and Saipin, S. (2017). The determination of nitrogen value at various reading points on rice leaf using RGB imaging. *Acta Hortic.*, 1152: 381-386.

Calders, K., Adams, J., Armston, J., Bartholomeus, H., Bauwens, S., Bentley, L.P., Chave, J., Danson, F.M., Demol, M., Disney, M. and Gaulton, R. (2020). Terrestrial laser scanning in forest ecology: Expanding the horizon. *Remote Sensing Environ.,* 251: 112102.

Escolà, A., Martínez-Casasnovas, J.A., Rufat, J., Arbonés, A., Sanz, R., Sebé, F., Arnó, J., Masip, J., Pascual, M., Gregorio, E. and Ribes-Dasi, M. (2015). A mobile terrestrial laser scanner for tree crops: point cloud generation, information extraction and validation in an intensive olive orchard. In: Precision agriculture'15. Wageningen Academic Publishers, 253-267.

Gholizadeh, A., Amin, M.S.M., Anuar, A.R., Aimrun, W. and Saberioon, M.M. (2011). Temporal variability of SPAD chlorophyll meter readings and its relationship to total nitrogen in leaves within a Malaysian paddy field. *Aust. J. Basic Applied Sci.,* 5(5): 236-245.

Gorbe, E., and Calatayud, A. (2012). Applications of chlorophyll fluorescence imaging technique in horticultural research: A review. *Scientia Horticult.,* 138: 24-35.

Noinongyao, P., Wattanapaiboonsuk, C., and Khantiviriya, P. (2018). Identification of plant nutrient deficiencies using convolutional neural networks. IEEE Conference paper, 1-4.

Patricio, D.I., and Rieder, R. (2018). Computer vision and artificial intelligence in precision agriculture for grain crops: A systematic review. *Computers Elect. Agric.,* 153: 69-81.

Raeva, P., Sedina, J., and Dlesk, A. (2018). Monitoring of crop fields using multispectral and thermal imagery from UAV. *European J. Remote Sensing,* 52(3): 1-10.

Rao, T.V.N. (2019). Prediction of soil quality using machine leaning techniques. *Int. J. Sci. Tech. Res.,* 8(11): 1309-1313.

Reckleben, Y. (2014). Sensors for nitrogen fertilization – Experiences of 12 years practical use. *J. Cultiv. Plants,* 66: 42-47.

Saberioon, M.M., Mohd Amin, S.M., Wayayok, A., Gholizadeh, A., and Anuar, A.R. (2013). Assessment of colour indices derived from conventional digital camera for determining nitrogen status in rice plants. *J. Food Agric. Environ.*, 11 (2): 655–662.

Xu, G., Zhang, F., Shah, S.G., Ye, Y., and Mao, H. (2011). Use of leaf color images to identify nitrogen and potassium deficient tomatoes. *Patt. Recog. Lett.,* 32(11): 1584-1590.

Yi, J., Krusenbaum, L., Unger, P., Hüging, H., Seidel, S.J., Schaaf, G., and Gall, J. (2020). Deep learning for non-invasive diagnosis of nutrient deficiencies in sugar beet using RGB images. *Sensors,* 20: 5893-5912.

Yogesh, Dubey, A.K., Ratan, R., and Rocha, A. (2019). Computer vision based analysis and detection of defects in fruits causes due to nutrients deficiency. *Cluster Computing,* 23: 1817-1826.

Yuzhu, H., Xiaomei, W., and Shuyao, S. (2011). Nitrogen determination in pepper (*Capsicum frutescens* L.) plants by color image analysis (RGB). *African J. Biotech.,* 10(77): 17737-17741.

Zhao, Y.X., Wang, K.R., and Bai, Z.Y. (2007). Research of maize leaf disease identifying system-based image recognition. *Sci. Agric. Sin.,* 40(4): 698-703.

Zubler, A.V., and Yoon, J.Y. (2020). Proximal methods for plant stress detection using optical sensors and machine learning. *Biosensors.,* 10: 193-220.

Smart Agriculture for Efficient Nutrient Management

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There is a revolution of sorts going on in the agricultural sector. Agriculture sector is one of the primary targets of this digital revolution that may well change the face of agriculture around the globe. Smart agriculture brings in the application of AI and machine learning, Internet of Things (IoT), sensors and robotics, remote sensing, and GIS for effective management of farms, ranging from fertilizer applications to irrigation scheduling to disease detection. It tends to encompass all walks of agriculture. Unlike other agriculture interventions, digital tools have the capability to connect the service provider and the farmer as well as the farmers and the consumer directly leading to more effective chain with minimal economic pilferage for all stakeholders. The basic idea here is to effectively manage the resources such as the nutrients, pesticides, water and labour. Theses technologies are designed so that the farmers can spend more time on the commercial aspects of their farms rather than on their operations. Agriculture's collaboration with technology could be the most transformational of all time. Agriculture is a sector that contributes significantly to a country's economic prosperity and stability apart from food and nutritional security.

Robotics in Agriculture

Agricultural robots are highly specialised pieces of technology that may aid farmers with a variety of tasks. They can assess, consider, and carry out a wide range of tasks, and they can be designed to adapt and develop to meet the demands of varied tasks. Agricultural robots are typically used to help farmers with jobs that are sluggish, repetitive, and boring. Robotic farming can assist farmers in concentrating their efforts on increasing total productivity. The tech companies are now focusing on utilization of robots in numerous agricultural operations such as harvesting, planting, weeding etc. Robots can play a key role in such operations. Robots and artificial intelligence can now do non-standard jobs previously reserved for human labour at cost-effective levels. Robotic vehicles are being used for land preparation and soil fertilization. German company Raussendorf has developed a robot named Cäsar, that can carry out soil fertilization both via a remote or autonomously. For autonomous operations it takes the help of a Global positioning system for accurate placements. The Greenbot robot can also carry out fertilization, land preparation and seeding operations. These robots are equipped with sensors that allow them to move autonomously in the field and avoid collisions. The sowing and planting robots are generally light weight designed to avoid soil compaction. The Australian Center for Field Robotics, University of Sydney developed the Di-Wheel robot. The Di-Wheel robot moves only on two wheels, decreasing the robot's size, weight, and mechanical complexity. This Di-wheel robot can carry out precision seeding as well as spraying and weeding. The distance between its two wheels can be adjusted based on crop requirements. Robots are also being designed for specifically identifying diseases and weeds and applying appropriate treatment. These robots apart from sensors have mounted cameras that can help them identify diseases and weeds. Many of these robots are designed to remove weeds by mechanical means, which can be of great help in farming systems where herbicides are not permitted.

Drones

Use of drones have significantly picked in various fields including that in agriculture. There is a great push for their use in India as well. Drones are like aerial robots who can be controlled remotely or work autonomously. In agriculture drones are mainly used for two distinct purposes commonly. One type of drones are involved in the spray of pesticides and nutrients over a field. These are effectively helpful for large fields and areas where labour is a problem. These drones have reservoirs that can be filled with fertilisers or pesticides for spraying. The whole application part is carried out in a fraction of the time that traditional methods take. The other type of drones are the one that are employed in surveillance, monitoring and imaging. Drones are being used for crop monitoring. With high resolution multispectral cameras mounted on these drones, local level imaging of farms has become a reality. These imageries can be processed to ascertain crop health. All of the utilities of a multispectral camera that remote sensing offers can achieved through these drone mounted multispectral cameras but at much higher resolution. This high resolution imageries ranging in few centimetres is highly effective in crop health monitoring. In soil monitoring and management, mounted sensors on drones can measure soil moisture content, topographical conditions, soil conditions, soil erosion, soil nutrients, and soil fertility.

Sensors

Sensors are ubiquitous now-a-days. Take for instance your smartphone which is loaded with variety of sensor carrying out different functions. All robots and drones are also depended on sensors for their autonomous activities. However, independent sensors that can track soil moisture content, soil nutrition etc. are also making way in agriculture. These are connected with IoT to provide field information to the farmers in real time. Irrigation sensors are one of the most commonly used thus enhancing the water use efficiency of the crops. Dielectric Soil Moisture Sensors measure moisture levels by measuring dielectric constant of the soil. Sensors can detect the moisture content in the soil and as an when it drops below the defined threshold and alert is sent to the farmer, who then can go for irrigation. Completely automated irrigation systems can irrigate on their own as when the sensors send signals for low moisture content in the soil.Sensor based irrigation systems consist of soil moisture sensor, soil temperature sensor, ambient humidity sensor, and ambient temperature sensor. Farmers are given irrigation recommendations based on these factors via a smartphone app. Soil data that is accurate and updated in real time has is of utmost importance to farmers, as these could help them schedule fertilizer application before losing precious time. This will help manage the nutrients efficiently reducing economic cost for the farmers both through increased yields and fertilizer savings, while reducing environmental pollution. Optical and electrochemical sensors give crucial information on pH and nutrient levels in the soil. Specific ions in the soil are detected using sensor electrodes and these are used to collect and analyze data which can be used for fertilizer scheduling. Multi-ion sensors can help predict spatial variations within a field in address site specific needs of the crops.

Remote Sensing and GIS

In comparison to above discusses technological interventions, remote sensing, and geographical information system (GIS) had been with us for a quite long time. Compared to very high resolution provided by the drone mounted multispectral cameras, the historical remote sensing in terms of aircraft and satellite mounted sensors have relatively lower resolutions. But they have been effective in managing natural resources effectively over larger areas. They have been really helpful in managing different farms. GIS on the other hand has played an important role in site-specific management of resources especially that of nutrients. Spatial variability maps of nutrients developed using GIS techniques help farmers in large farms to rationalize fertilizer application in different zones. These applications are based upon the soil test values mapped for the entire farm using GIS. Variable rate technology permits fertiliser, pesticides and various other inputs to be applied at varied rates across a field based upon the digital spatial variability maps of the farm. GIS and remote sensing coupled have been used extensively to map resources including nutrients and land use variations/changes.

Artificial Intelligence, Machine Learning and Internet of Things

Sensors whether stand alone or vehicle mounted gather enormous amounts of farm data in real time. Artificial Intelligence (AI) and Machine Learning (ML) thrive on big data. This data can play an important role in deciding how the sensor-based systems can actually execute operations on ground. It helps in deciding the time of sowing, the right time of fertilizer applications, as and when there is a need to check the proliferation of disease before it reaches threshold level etc. Vast amounts of farm data, on soils, moisture, crop yields, crop growth patterns, animals etc. is processed through AI and ML models to arrive at possible actionable results. The harvesting robots use AI to pick up the fruits ready to be harvested based upon the data they have been fed, which helps them to decide the right time to pick. Similarly, the weeding robots are fed with images of the weeds which helps them identify those weeds. Even the vast amounts of remote sensing data obtained from satellite mounted sensors is being used to bring out high quality digital soil maps with the help of machine learning models, as a number of variables obtained over the target area are used to support the soil data. However, all this needs to be connected in real time for best possible results. And there comes in Internet of Things (IoT). IoT tends to combine all the elements in an automated or a semi-automated system. For instance of sensor based irrigation system the information recorder by the sensor had to be further sent to the farmer, which he receives on an app in his smartphone and takes the action accordingly, possibly triggering irrigation through another app on his phone.

However, most of these smart technologies are still a long way from the common farmer, especially in developing countries. As one of the shows on Netflix reiterates time and again "The future is already here, It's just not evenly distributed" (Sisyphus on Netflix). It is so true for the everyday life that we live in. Underdeveloped and developing countries still have to do a lot of catching when it comes to smart agriculture tools. From the days of the big machinery revolution in agriculture which the developing world failed to catch up on owing to the vast majority of reasons that included smallholdings and resource-poor farmers. This, however, is different as the cost of services and hardware are bound to decline with increased production. With smartphones becoming ubiquitous and rapid developments in the world of sensors, things look positive for a common farmer. Our goal is to provide solutions that are not just effective but also affordable and more suited for smallholder farmers.For Instance, Remote sensing has been with us now for quite a long. However, its applications are still very limited and mostly focused on large area solutions benefitting policy-making and large farm holders. However, with the advent of drone-mounted sensors giving image resolution of as low 1 sq cm, the possibilities of managing small farms seems very real. Not only that such fine resolution holds the promise to be extremely precise in detecting deficiencies and disease occurrences further reducing resource applications while delivering solutions directly to your smart phones.

Sustainability of agricultural production systems means the sustainability of the environment around us in which the farmers practice their agriculture. Agriculture contributes significantly to environmental issues, be it emissions of methane from paddy fields or release of nitrous oxide from overuse of nitrogenous fertilizers to contamination and eutrophication of water bodies. Vast chunks of arable land degrade every year due to improper agricultural practices, leading to further encroachment of natural forest lands around the globe. Increasing temperatures and changing rainfall patterns are throwing new challenges every day. Proper management of resources holds the key to sustainable eco-systems. With smart solutions, this can be achieved much more effectively through a reduction in the utilization of resources, effective management of our soils as well as crops while reducing the pressure on land.

Weed Management Options for Sustainable Agriculture

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The world population has rapidly exceeded seven billion and is expected to reach nine billion by 2050. Current crop production levels are not adequate to feed the growing population, and meeting this anticipated demand could be a huge challenge for humanity. Climate change, the scarcity of arable land and water resources and the threat from diseases, pests and weeds are additional issues that make the pressure on agricultural systems greater than ever before, with implications, in the short and long-term, for sustainability, for the planet and for the quality of life of living beings. Weeds have been a persistent problem in agriculture since its beginning. Weeds hinder the growth of crops by competing with the plants for water, nutrients and sunlight, which results in large losses in crop production. Weed management takes away nearly one third of total cost of production of field crops. In India, the manual method of weed control is quite popular and effective. Of late, labour has become non-availability and costly, due to intensification, diversification of agriculture and urbanization. Most weeds are either controlled mechanically through specific cultivation practices or with the application of herbicides. However, intensive mechanization increases soil erosion, leading to a loss of fertility. The use of herbicides contaminates the soil, water, food and air, causing diseases in humans and animals, creating the phenomena of herbicide resistance and unbalancing ecosystems. The complexity of these situations has resulted in a need to develop a wholistic sustainable eco-friendly weed management programme throughout the farming period. Sustainable development is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable. Sustainable weed management is the use of weed control methods that are socially acceptable, environmentally benign and cost-effective.

Objectives of sustainable weed management

There are several basic objectives of the sustainable weed management. The main objectives are:

- To make best use of the resources available for weed control
- To develop cultivation methods that manage weeds and improve soil quality and to determine the impact of weed management systems

- To minimize use of non-renewable resources like herbicides and to use of renewable energy and recycled mineral resources
- To protect the health and safety of farm workers and animals, local communities and society from the application of chemicals
- To protect and enhance the environment and natural resources
- To protect the economic viability of farming operations
- To provide sufficient financial reward to the farmer to enable continued production and contribute to the well-being of the community
- To produce sufficient high-quality and safe food
- To build on available weed control technology, knowledge and skills in ways that suit local conditions and capacity

Approaches involved in sustainable weed management

There are three different approaches involved in sustainable weed control management. The different approaches are reviewed in the context of the cultural, mechanical and biological methods, respectively.

Cultural approaches

Proper crop stand: Crop population, spatial arrangement, right method and time of sowing, adequate seed rate and the choice of cultivar (variety) are essential to limit the weed growth. Any crop variety that is able to quickly shade the soil between the rows and is able to grow more rapidly than the weeds will have an advantage in weed management.

Green manure *in situ*: A practice of ploughing or turning into the soil undecomposed green manure crops in the same field where the crop is grown. Green manure crops are commonly associated with organic agriculture and are considered essential for annual cropping systems that wish to be sustainable.

Intercropping: Growing of two or more generally dissimilar crops simultaneously on the same piece of land, in distinct row arrangement is known as intercropping. Intercropping and cover cropping are practices that increase diversity in the cropping system and enhance the utilization of resources such as light, heat and water. These practices can also help to suppress weeds and increase the likelihood of being able to reduce herbicide use in the cropping system. Alternatively, in organic or other systems where herbicides are not used, intercropping and cover cropping can reduce the yield loss potential and provides stability in the system.

Crop rotation: Crop rotation is an important component of integrated weed management. The choice and sequencing of crops affect long term weed population dynamics and consequently weed management. Crop rotation is a planned sequence of crops growing in the same field year after year. Rotating crops adds diversity to the cropping system, increasing the sustainability of the system. Crop rotation provides the foundation for long-term weed management.

Organic manures: A by-product of the processing of plant and animal matter that has sufficient nutrient capacity to have value as fertilizer. Application of cane press mud and neem cake reduced the weed seedbank of *Cyperus rotundus*, *Echinochloa colonum* and *Trianthem aportulacastrum* in maize, due to reduced pH and phytonicidal properties of organic manures.

Mechanical approaches

Off-season ploughing: Ploughing operations carried out in the off-season with the help of tractors or bullock drawn implements known as off-season ploughing, before the crops are sown or transplanted. Off-season ploughing twice at 45 days interval was found to be superior in reducing the population of weeds; *Cyperus rotundus*, *C. difformis*, *Sphenoclea zeylanica* and *Fimbristylis littoralis* and highest weed control index in succeeding rice crops. Mechanical destruction of existing weed vegetation in the summer and exposure of reserves of weed seeds or propagules and subsequent scorching contributed for superior performance of summer ploughing in controlling weeds during succeeding crop seasons.

Soil solarization: Soil solarization is a method of hydrothermal disinfection accomplished by covering moist soil with transparent polyethylene (TPE) film during the hot summer months. Solarization during the hot summer months can increase soil temperature to levels that kill many disease-causing organisms(pathogens), nematodes and weed seed and seedlings. Itleaves no toxic residues and can be easily used on a small or large scale. Soil solarization also improves soil structure and increases the availability of nitrogen and other essential plant nutrients. The basic phenomenon helping weed control upon soil solarization is build-up of lethally high temperatures in top soil where most of the dormant and viable weed seeds are present. The possible mechanisms of weed control by soil solarisation are breaking dormancy of weed seeds and solar scorching of emerged weeds and direct killing of weed seeds by heat.

Stale seed bed: It is the technique in which the weed seeds are allowed to germinate by rain or wetting and killing them (at 1-2 flushes of the weeds) before sowing seeds of main crops. At this stage a shallow tillage or anon-residual herbicide like paraquat may be used to destroy the dense flush of young weed seedlings. This may be followed immediately by sowing a desired crop. The main objective with this technique is that most of the weeds that have the potential to germinate, because of their placement in the upper 1" to 2" of the soil, will usually do so within two weeks after the soil is prepared.

Use of weeders: Now a days, use of mechanical weeders in agricultural operations is increasing because of non-availability of labours for weeding. The cost of the weeding operations is also reduced by using the machineries for weeding. The machineries like mini-weeders, power tillers, mini-tractor drawn rotavator are used for weeding in wider spaced crops like sugarcane, cotton and orchards.

Mulching: Mulches are coverings placed on the surface of the soil. Mulching smothers the weeds by excluding light and providing a physical barrier to impede their emergence. Any material such as straw, plant residues, leaves, loose soil or plastic film can be used as a mulching material. Such materials as straw, bark and composted material can provide effective weed control. Producing the material on the farm is recommended since the cost of purchased mulches can be prohibitive, depending on the amount needed to suppress weed emergence. An effective but labour-intensive system uses newspaper and straw. Organic mulches have the advantage of being biodegradable.

Biological approaches

Allelopathic plants: The concept of allelopathy is receiving increased attention in the search for weed control strategies. Allelopathy is any direct or indirect effect by one plant, including micro-organisms, on another through production of chemical compounds that escapes into the environment to influence the growth and development of neighbouring plants. Plant releases chemicals that show allelopathic potentiality are called allelochemicals or allochemicals. It covers a wide range of chemicals used by plants or organisms. Generally different plant organ such as plant tissues, including leaves, flowers, fruits, stems, roots, rhizomes, seeds and pollen are the main sources of allele-chemicals of donor plants are in stressed or competing with neighbouring plants, that released through crop-environmental ecological process.

Bio-fertilizers: Bio-fertilizers are defined as preparations containing living cells or latent cells of efficient strains of microorganisms that help crop plants uptake nutrients by their interactions in the rhizosphere when applied through seed or soil. They accelerate certain microbial processes in the soil which augment the extent of availability of nutrients in a form easily assimilated by plants.

Insect bio-control agents: Bio-control of weeds is the deliberate use of natural enemies to reduce the densities of the weeds economically or aesthetically tolerable limits. Insects are important in biological control because of their, Great variety and numbers, High degree of host specialization, Intimate adaption to their hostplants, Availability of a range of natural enemies suited to particular ecological situations and ease with which they can be handled. There are two kinds of biological control: Classical and inundative.

Bio-herbicides: Weeds can be controlled by pathogens like fungi, bacteria, viruses and virus like agents. Among the classes of plant pathogens, fungi have been used to a larger extent than bacteria and virus or nematode pathogens. A bio-herbicide is a preparation of living inoculums of plant pathogens formulated and applied in a manner analogous to that of an herbicide in an effort to control or suppress the growth of weed species.

Herbicide resistant crops: Herbicide resistance is the inherited ability of the plant to survive and reproduce following exposure to a dose of herbicide that would normally be lethal to the wild type. In a plant, resistance may occur naturally due to selection or it may be induced through such techniques as genetic engineering.

Integrated weed management: One of the definitions of Integrated Weed Management (IWM)implies methods of controlling weed that require no herbicide or rational use of herbicides. IWM includes more than one method of control viz., seed purity, crop varieties, spacing and methods of planting, cultivation, soil solarization, intercropping, crop rotation, water management, manure application, biological control and herbicides. According to FAO, “the integrated campaign against pests is a method whereby all economically, ecologically and toxicologically justifiable methods are employed to keep the harmful organisms below the threshold level of economic damage, keeping in the foreground the conscious employment of natural limiting factors.

Benefits of sustainable weed management

- Improved soil and water conservation
- Mitigation of global warming
- Enhanced biodiversity
- Reduction of persistent pollution
- Increased food nutrient density
- Reduced toxic load in adults and children who eat organic
- Better conditions for farmworkers
- Competitive yields
- Price premiums
- Direct-to-consumer marketing channels
- Lower input costs
- Higher per farm income
- Improved resilience or lower volatility
- Energy savings and
- Income from carbon markets

Thus, the sustainable management of the agricultural system, namely of weeds, is an important issue for the present and future of humanity. In addition to integrated management, the development of precision technologies inherent to weed control can be a valuable contribution to improved sustainability and agricultural yield. In this sense, a more effective involvement of researchers and farmers with the integration of ecological and technological principles into weed management decision making is important.

References

Monteiro, A.; Santos, S.(2022).Sustainable Approach to Weed Management: The Role of Precision Weed Management.*Agronomy*,12, 118.https://doi.org/10.3390/agronomy12010118

Gnanavel, I.(2015). Eco-Friendly Weed Control Options for Sustainable Agriculture. *Science International*,3(2): 37-47. DOI: 10.17311/sciintl.2015.37.47

Revisiting the Nutrient Composition of Composts Prepared with Prevailing Practices in Bhagalpur

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Soil fertility maintenance is very essential in achieving and maintaining high crop yields over a period of time but due to the decline in soil fertility it is becoming increasingly critical to secure sustainable soil productivity. Fertilizer is an important input that contributes to crop production. The continuous use of mineral fertilizers has created potential polluting effects in the environment (Oad *et al.,* 2004) and also resulted in depletion of soil organic matter (Madeley, 1990) and consequently reduction in crop yield and serious degradation and decline in soil productivity (Adediran *et al*., 2004). On the other hand, the use of organic fertilizer in agriculture preserves the ecosystem in the sense that fertility is usually maintained and there is also improvement in the physical and biological properties of the soil. Cow dung and poultry manure are mostly used by farmers who engage in mixed farming so, in effect, there is no or little waste generated. Organic manure when efficiently and effectively used ensures sustainable crop productivity by immobilizing nutrients that are susceptible to leaching (Abou El-Magd *et al*., 2006) and as well attracts low cost. Organic matter is one of the most important components influencing the physical, chemical and microbiological properties of soil to a great extent. All physical properties of soil are affected by changes in organic matter levels of soil. Decrease in bulk density with the addition of organic matter has been reported. The application of FYM @ 7 t/ha to both rice and wheat crops continuously for 8 years increased organic carbon levels from 1.4 to 1.6 percent. Green manuring increased the content of available nitrogen and potassium but decreased the base saturation of soil. Application of farm yard manure in paddy fields provides nutrient recycling. N and P utilization by rice also significantly improved with the application of green manure. Application of organic manures have significant effect on growth and development of crop plants. The residual effect of FYM applied to preceding crop of rice/wheat has been proved to be significant on plant growth of the succeeding crop over no FYM. One of the current challenges is to quantify the mechanisms, capacity and longevity of C stabilization in agricultural lands. Currently, crop-based agriculture excluding pastureland, occupies 1.7 billion hectares globally (Paustian *et al.,* 1997). It is estimated that 111 to 170 Pg C or approximately 10 percent of the earth's total soil C (1500 Pg) (Post *et al.,* 1990; Eswaran *et al.,* 1993) is stored within agricultural soil. Revived interest in SOC is due partly to its role as an important indicator of soil quality (Gregorich and Carter, 1997; Lal, 1997). Farming systems that utilize best management practices hold promise for sequestering soil C, which has the potential to enhance agricultural sustainability, reduce negative environmental impacts and attenuate anthropogenic carbon dioxide emissions. If the potential benefits of SOC sequestration are to be validated, then there exists a substantial need to elucidate and accurately quantify the underlying processes, capacity and longevity of C pools in agricultural lands. Studies have shown that increase in SOC levels are directly linked to the return of fresh organic material to soil. (Rasmussen *et al.*, 1980; Cole *et al.*, 1993).

Based on a survey of composting sites in 6 blocks of Bhagalpur, information about composting materials and methodology adopted by farmers was collated. Most of the farmers apply urea and DAP on their compost heaps because they beleive that after application of chemical fertilizers, the rate of composting could be improved. Some farmers apply phosphatic fertilizers to improve the C:P ratio of composts. The time of application of chemical fertilizers by them is not fixed but the application is usually made sometime during the composting process.

Farmers often add commonly available weed plants in the composting pits or heaps. They don’t bother about the volume and weight of weed plants added to the composting units. The weed species that are used by farmers for composting include *Achyranthus aspera L., Amaranthus viridis L., Anagalis arvensis L, Argemonne Mexicana, Azoratum conyzoidis, Brassica compestris L., Cajanus cajan, Canabis sativa L., Cephalandrus indica, Calotropis procera Ait, Cassia tora, Chenopodium album L., Crotonus sparsiflora, Cuscuta reflexa Roxb, Cynodon dactylon L., Cyperus rotundus, Echhornia, Eclipta alba L., Euphorbia helioscopia L., Fumaria parbiflora, Gomphorina silosoides, Hemisdesmus indicus, Ipomoea nil L., Lantana camara, Lathyrus odoratus, Lathyrus sativus, Lepidium sativum L., Mollugo pentaphylla L., Nicotiana tobaccum L., Oxalis corniculata L., Parthenum hysterophorus L., Phalaris minor, Phylla nodiflora, Phyllanthus urinaria L., Pisum sativum, Porttulaca olaracee, Ranunculus arvensis L., Solanum melongana L., Solanum nigrum L., Solanum tuberosum L., Spergula arvensis, Viccia fava,* and *Viccia sativa L.*

The pH of composts prepared by farmers varies from 7.21 to 7.60 and the EC (dS m^{-1})of compost samples varies from 1.37 to 1.89 Farmers make their compost either in unlined composting pit or make heap of the materials on open land which is not used for cultivation purpose. The types and quantities of waste inputs are potentially important factors’ influencing the chemical properties of farmer’s produced composted residues in small-scale composters.

The mean total nitrogen content of the composts prepared by farmers varied from 0.5 to 0.7 per cent, whereas that of P and K varies from 0.24 to 1.11 per cent and 0.89 to 1.30 per cent respectively. The per cent content of sulphur in farmers prepared compost varied from 0.19 to 0.53 per cent. The total content of various micronutrients including Cu, Mn, Fe and Zn in the composts varied from 15.89-39.67 ppm, 180.89-805.78 ppm, 1140.33 to 4435.89 ppm and 36.33 to 107.56 ppm. This range in the nutrient contents is both because of the variation in the nutrient contents of the substrates as well as due to the widely varying composting conditions and methods.

From the point of view of nutrient management for agricultural crops using the farm wastes and crop residues, the cattle dung along with crop residues and some weed plants could potentially very well be used as a substrate for composting. But for efficient composting, selection of the most appropriate bedding material in the animal sheds is an important consideration. Widely varying nutrient contents and quality of the farmers prepared composts suggests that if farmers are provided with the good composting technology, their traditional methods can be improved. Addition of organic wastes including vegetable, kitchen and garden waste materials along with chemical fertilizers should also be resorted to in order to make good quality and nutrient rich composts.

References

Abou E.l.-Magd, M.A., M. Hoda, A. Mohammed and Z.F. Fawzy (2005) Relationship, growth and yield of broccoli with increasing N, P or K ratio in a mixture of NPK fertilizers. *Ann. Agric. Sci. Mosht*. **43**: 791-805.

Adediran, A.O., I. Parcharidi S., M. Poscolieri, and K. Pavlopoulos (2004) Computer-assisted discrimination of morphological units on north-central Crete (Greece) by applying multivariate statistics to local relief gradients. *Geomorphology***58**: 357-370.

Gregorich, E.G., Carter, M.R., Doran, J.W., Pankhurst, C.E., Dwyer, L.M. (1997) Biological attributes of soil quality. *In*: Gregorich, E.G., Carter, M.R. (Eds.), Soil Quality for Crop Production and Ecosystem Health. New York, NY, 81-114.

Lal R (1997) Degradation and resilience of soils. *Philos Trans R Soc Lond B***352**:997–1010.

Madeley J., (1990) The organic cycle In African Farming and Food Processing: May/June. Alain Charles Publishing Ltd. London, *National Fertilizers* 22.

Oad F.C., U.A. Buriro and S.K. Agha (2004) Effect of organic and inorganic fertilizer application on maize fodder production. *Asian J Plant Sci*., **3**: 375-377

A.V. Barker, (1997) Composition and uses of compost, agricultural uses of by-products and wastes ASC Symposium Series, *Am. Chem. Soc*. **668**: 140-162.

Abou E.l.-Magd, M.A., M. Hoda, A. Mohammed and Z.F. Fawzy (2005) Relationship, growth and yield of broccoli with increasing N, P or K ratio in a mixture of NPK fertilizers. *Ann. Agric. Sci. Mosht*. **43**: 791-805.

Acharya, C.L., O.C. Kapur. (2001). Using organic wastes as compost and mulch for potato (Solanum tuberosum) in low water-retaining hill soils of north-west India. *Indian Journal of Agricultural Science***71** (5): 306–309.

Bernai, M.P., Paredes, C., Sánchez-Monedero, M.A., and Cegarra, J., (1998) "Maturity and stability parameters of composts prepared with a wide range of organic wastes", *Bioresource Technology*, **63**(1): 91-99.

Bernal, M.P., Alburquerque, J.A., Moral, R. (2009). Composting of animal manures and chemical criteria for compost maturity assessment. a review. *Bioresource Technology*. **100**, 5444-5453.

Bernal, M.P., C. Paredes, M.A. Sanchez-Monedero, and J. Cegarra. (1998). Maturity and stability parameters of composts prepared with a wide range of organic wastes. *Bioresource Technology***63**: 91–99.

Beucha, L. (2006) Vectors and conditions for preharvest contamination of fruits and vegetables with pathogens capable of causing enteric diseases. *British Food Journal*. **138**: 38-53.

Cheng, Y., Chefetz, B., Heemest, J., Romaine, P. & Hatcher, P. (2000) Chemical nature and composition of compost during mushrooms growth. *Compost Science and Utilization*. **8**(4): 347.

Chhonkar, P.K. and K.V.B.R. Tilak. (1997). Plant nutrients Need, supply, efficiency and policy issues 200–2025. Kanwar, J.S. and Katyal J.C (Eds). National Academy of Agricultural Sciences, New Delhi.

Ciavatta, C., Govi, M., Vittori, A.L., Sequi, P. (1990). Characterization of humified compounds by extraction and fractionation on solid polyvinylpyrrolidone. *Journal of Chromatography*. **509**, 141-146.

Fourti O., Jedidi N. and Hassen A. (2011) Comparison of methods for evaluating stability and maturity of co-composting of municipal solid wastes and sewage sludge in semi-arid pedo-climatic condition. *Nat Sci.;***3**:124–135.

Gao, M., Li, B., Yu, A., Liang, F., Yang, L., Sun, Y. (2010). The effect of aeration rate on forced-aeration composting of chicken manure and sawdust. *Bioresource Technology*. **101**, 1899-1903.

Gaur, A.C. (1999). Microbial technology for composting of agricultural residues by improved methods. Indian Council of Agricultural Research (ICAR), New Delhi.

Gautam S.P., Bundela P.S., Pandey A.K., Awasthi M.K. and Sarsaiya S. (2010) Composting of municipal solid waste of Jabalpur city. *Global J Environ Res*. **4**: 43–46.

Kumar, M., Ou Yan, L., Lin, J.G. (2010). Co-composting of green waste and food waste at low C/N ratio. *Waste Management*. **30**, 602-609.

Lal R (1997) Degradation and resilience of soils. *Philos Trans R Soc Lond B***352**:997–1010.

Liang, C., Das, K.C., McClendon, R.W. (2003). The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend. *Bioresource Technology***. 86**, 131-137.

Lucimar Lopes Fialhoa, Wilson Tadeu Lopes da Silvaa, Débora MBP Miloria, Marcelo Luiz Simõesa and Ladislau Martin-Neto (2010) Characterization of organic matter from composting of different residues by physico-chemical and spectroscopic methods, *Bioresource Technology*, (6), 1927.

M. Leaon, (1995) Adapted fromOrganic Materials Management, California Integrated Waste Management Board.

M. Tejada, C. Garcia, J.L. Gonzalez, M.T. Hernandez (2006) Use of organic amendment as a strategy for saline soil remediation: influence on the physical, chemical and biological properties of soil, *Soil Biol. Biochem*. **38**: 1413–1421.

Crop Residue Management for Nutrient Supplementation in Cereal-Vegetable-Pulse Cropping System Followed in an*Inceptisols*-A 10-year Case Study

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Introduction :

India is an agrarian based country with more than sixty per cent of the population engaged in agriculture and allied services, contributing 18 per cent of the country’s gross domestic product (GDP).The agricultural sector in India generates a large volume of crop residues (Pandit *et al.*, 2020). The distribution and availability of the residues are highly spatiotemporal due to diversity in the cropping practices and agroclimatic conditions across the country. According to Hiloidhari*et al.* (2014) the gross crop residue in India was 686.2 Mt, out of which 234.5 Mt (34.2 %) surplus residues were available for use(Table 1).

The gross crop residue potential of 1055 Mt yr^{-1} could be achieved by including residue from species and plantation crops*viz*; rubber and coffee (Singh and Gu, 2010). The 60 to 70 per cent of daily diet of animal is from crop residues. The crop residues apart from animal fed are also used for compost, manures, mulches, raw materials for pulp and paper industry, and preparation of packaging material. Presently India faces a net deficit of 35.6 per cent green fodder, 10.95 per cent dry crop residue and 44 per cent of concentrate feed ingredients annually. Considering the N-P-K content of 0.5-0.2-1.5 per cent of crop residues respectively, the agricultural crop residues can replace 6.5 Mt of chemical fertilizers equivalent to 25 per cent of total N-P-K requirement in the country (Choudhury, 2018). The Indian economy is predominantly rural and agriculture oriented. The farmers concentrate mainly on crop production in India and other enterprises like diary, fishery, poultry, duckery, agroforestry, goat and sheep and pig rearing are supportive in gross income from which huge amount of secondary product remain as agricultural waste like crop residue, animal dung, poultry litter, fish waste (scale, gills, elementary canal, etc.). These are untapped future resources in agriculture.The integrated use of biofertilizers with inorganic and organic sources of nutrientshelp maintaining soil fertility (Sethi *et al.,* 2021, Sethi *et al.*, 2017).Liming of acid soils also enhances the bioavailability of essential plant nutrients which leads to higher crop yield and maintain better soil health (Pattanayak and Sarkar, 2016).

Table 1: Crop wise gross and surplus residue potential in India

Crop group	**Gross residue (Mt)**	**Surplus residue (Mt)**
Cereal	367.7	90.1
Oilseed	48.8	13.7
Pulse	17.9	4.83
Sugarcane	110.6	55.70
Horticulture(Banana, Coconut, Arecanut)	61.4	22.50
Others (Cotton and jute)	79.8	47.30
Total(Mt)	686.2	234.5(34.2)

(Source: Hiloidhari*et al.* 2014)

In a long term experiment (10 years) the influence of INM practices including use of fertilizers based on soil test (STD), FYM (@ 3.0-5.0 t ha^{-1}), vermicompost (@ 1.5-3.0 t ha^{-1}), biofertilizers (*Rhizobium*, Azotobacter, *Azospirillum*, and PSB) and lime(@0.1/0.2LR) were studied in different combinations of practices in sandy strongly acidic (pH-5.14) *Inceptisols* followed in cereals (maize/ragi)– vegetables (cabbage/ cauliflower/ knolkhol) - pulses (green gram/ cowpea) cropping system, where the crop residues were incorporated in-situ (Table 2) as a result of which considerable amount of major nutrients could be recycled and helped maintaining soil nutritional fertility for crop production.

Table 2: Residue incorporation and nutrient recycled under long term (10 years) INM practices followed in cereal-vegetable-pulses cropping system.

Package of practices	**Residue (dry) incorporation**	**Nutrient cycled**					
		N	**P**	**K**	**Ca**	**Mg**	**S**
	(t ha^{-1} yr^{-1})	**(kg ha^{-1} yr^{-1})**					
Control	1.60	317	77	386	273	141	67
STD	1.84	452 (19) *	98 (18)	548 (48)	339	174	91 (20)

STD + F	1.92	734 (25)	195 (21)	861 (52)	720 (84)	275 (64)	149 (24)
STD +VC	1.98	729 (25)	185 (22)	834 (51)	697 (94)	265 (66)	144 (23)
STD+F+BFs	1.99	800 (28)	192 (23)	900 (55)	739 (86)	309 (72)	171 (27)
STD +VC+BFs	2.03	813 (28)	215 (25)	998 (61)	709 (95)	328 (82)	167 (26)
STD+F+L+BFs	2.14	867 (30)	229 (27)	1026 (63)	810 (18)	382 (42)	190 (30)
STD+VC+L+BFs	2.25	869 (30)	231 (27)	1001 (62)	900 (21)	400 (21)	201 (32)
LSD (p=0.05)	0.07	54	12	59	41	23	9.4

*Data in the parenthesis indicate per cent of total added during the year (Source: Jena, 2021)

Table 3: Post harvest soil nutrients under the influence of 10 years INM practices followed in cereal-vegetable-pulse cropping system.

Package of Practices	**Postharvest Soil Properties**							
	pH	**OC**	**Available nutrients**				**Exchangeable**	
			N	**P**	**K**	**S**	**Ca**	**Mg**
		g kg^{-1}	**(kg ha^{-1})**				**(cmol (p+) kg^{-1})**	
Control	5.73	4.50	113	9	131	12.0	1.6	1.01
STD	4.94	4.48	140	25	149	10.3	1.3	1.14
STD + F	5.36	5.10	132	18	140	13.1	1.9	1.62
STD +VC	5.38	5.00	142	19	142	14.2	1.7	1.61
STD+F+BFs	5.19	5.75	136	25	153	15.7	2.2	1.08
STD +VC+BFs	5.23	5.70	140	27	163	17.6	2.6	1.01
STD+F+L+BFs	6.04	6.08	157	36	181	19.0	4.4	2.88
STD+VC+L+BFs	6.03	6.39	174	30	195	19.9	4.6	2.89
LSD (p=0.05)	0.46	0.72	6.4	6.7	7.1	1.8	0.17	0.07
Initial	5.17	3.91	207	37	85	25.5	4.0	2.4

(Source: Jena, 2021)

Significant amount of crop residues could be incorporated through package of practices (POPs) receiving inputs integrated with soil test-based fertilizers (STD). Fifteen per cent (15%) higher residue could be generated with STD practice compared to no input integration practice i.e., control (1.16 t ha^{-1}). Organics (F/VC) integrated with STD generated 4.4 to 7.6 per cent more biomass than no organics integration (1.84 t ha^{-1}). Integration of BFs use generated 2.5 to 3.7 per cent more crop residues. However, integrating liming practice in acid soil for amelioration generated 7.6 to 10.8 per cent higher residue biomass.

The residue generated in respective practices could recycle N ranging from 317 to 869 kg ha^{-1} yr^{-1}. P from 77 to 231 kg ha^{-1} yr^{-1}, K from 386 to 1001 kg ha^{-1} yr^{-1}, Ca from 339 to 900 kg ha^{-1} yr^{-1}, Mg from 141 to 400 kg ha^{-1} yr^{-1}and S from 67 to 201 kg ha^{-1} yr^{-1}, lowest with control practice and highest with lime, organics and BFs integrated practice. On an average irrespective of the POPs adopted 26.7 per cent of added N, 23.3 per cent of added P, 56.4 per cent K, 66.6 per cent Ca, 62.6 per cent Mg and 26.1 per cent of added S could be recycled back through crop residue incorporation into the soil (Table 2).

Not only the nutrients could be saved but also there was build up of organic carbon, available K in soil compared to initial year content (2010). Fertilizers recommendation based on soil test prevented accumulation of available P in the experimental soil otherwise there was depletion of status. Liming practice in complete INM package helped maintaining higher exchange status for Ca and Mg in spite of crop removal and other possible losses. In spite of N supplementation through fertilizers and residue incorporation the available N status could not be maintained at higher status compared to initial year (207 kg ha^{-1}). Similar was the fact about the available S in post-harvest soil (Table 3).

Conclusion:

The integrated nutrient management practice combining the use of soil test-based fertilizers, organics, BFs, and liming of acid soil not only produced more yield (data not presented) but also had batter soil health for future use. The *in-situ* in corporation of crop residues resulted in addition of nutrients through decomposition and simultaneous carbon build up. The residue recycling practice enhanced the soil fertility status by improving/ maintaining soil chemical and nutritional properties.

References

Choudhury, S. (2018) Modern Concept of Farm Waste management (Chapter-7). http://doi.org/10.22271/ed book 01.a07.

Hiloidhari, M., Das, D. and Baruah, D. C. (2014) Bioenergy potential from crop residue biomass in India. *Renewable and Sustainable Energy Reviews*32, 504-512.

Jena, M.K. (2021) Long term effect of integrated nutrient management practices under intensive cropping on crop productivity and soil properties of an acid upland *Inceptisols*. PhD thesis submitted to Odisha University of Agriculture and Technology, Bhubaneswar, India.

Pandit L, Sethi D., Pattanayak S.K. and Nayak Y. (2020) Bioconversion of lignocellulosic organic wastes into nutrient rich vermicompost by *Eudriluseugeniae. Bioresource Technology Reports* 12, 100580.

Pattanayak SK and Sarkar A. (2016) Sustainable management of Acid Soils: Technologies and their Transfer. *Indian Journal of Fertilisers*12, 16–24.

Sethi D, Mohanty S, Pradhan M, Dash S. and Das R. (2017) Effect of LD slag application on yield, yield attributes and protein content of groundnut kernel in an acid soil of Bhubaneswar. *International Journal of Farm Sciences* 7, 79–82.

Sethi D, Subudhi S, Rajput VD, Kusumavathi K, Sahoo TR, Dash S, Mangaraj S, Nayak DK, Pattanayak SK, Minkina T, Glinushkin AP. and Kalinitchenko VP. (2021). Exploring the Role of Mycorrhizal and Rhizobium Inoculation with Organic and Inorganic Fertilizers on the Nutrient Uptake and Growth of *Acacia mangium* Saplings in Acidic Soil, *Forests* 12, 1657. https:// doi.org/10.3390/f12121657.

Singh, J. and Gu, S. (2010) Biomass conversion to energy in India -A critique. *Renewable* and *Sustainable Energy Reviews* 14, 1367-1378.

Forest Soils Road to 4 Per Mille Carbon

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Introduction

Soil is a complex mixture of mineral nutrients, water, air and organic matter (Well and Brady, 2017). It provides a substratum for all living organisms in the terrestrial ecosystem (Lal, 2008). Soil sustains healthy vegetation and plays a significant role in an organism's food and life cycle, being a nutrient reserve and carbon pool. Forest soils are unique due to the deep-rooted plants, decomposing litter, organic matter recycling and presence of soil organisms (Boyle, 2005). Forest soils are characterised by organic humus layers L, F, H and woody debris, and they harbour microorganisms beneficial to decomposition. Besides, forest soils regulate the global carbon cycle by sequestering a significant amount of carbon stock from the atmosphere (Shapkota and Kafle, 2021). Despite the importance, now-a-days, forest soils are facing threats that may be natural (drought, storm and wildfire) or anthropogenic (deforestation, fragmentation and pollution) (Wilpert, 2022). COP 21 launched the "4 per mille Soils for Food Security and Climate" to increase global soil organic matter stocks by 4 per 1000 (or 0.4 %) per year as a compensation for the global emissions of greenhouse gases by anthropogenic sources (Minasny*et al*., 2017). Forest soils are far way apt for achieving the goal of 4 per mille compared to other agricultural lands.

Forest soil: peculiar features and importance

Forest soils are porous, aggregated, well-differentiated soils with plenty of organic matter. Although they are thin, less fertile and stonier than soils from other land-use forms, they provide mechanical anchorage to trees (Burst, 2020). Forest soils are pivotal in the functioning of the ecosystem, nutrient storage and decomposition. Also, they ensure a consistent supply of forest resources, especially vegetation, nutrients, water and oxygen (to roots). Thus, forest soil is the central "coordinating entity" for most ecosystem services (Wilpert, 2022).

Forests are efficient nutrient recyclers. Nutrients from the unreachable soil layers absorbed through deep-rooted plants will be stored as biomass or reach the surface soil through litterfall. Forest floors, covered with organic residues in various stages of decomposition, make a typical habitat for several soil-dwelling organisms (Takahashi, 2021). Compared to other land-use types, deeper reaching rooting zone and high activity of microbes, soil fauna, and plant roots in forest soil result in high humus contents that make it over-proportionally porous (Sokołowska*et al*., 2020). Moreover, the high demand of trees and soil biota for essential nutrients like phosphorous and nitrogen leads to low leaching rates of those elements in most forest soils (Makowski *et al*., 2020).

The litter layer in forest soils acts as a blanket, and it prevents soil erosion and increases soil water-holding and infiltration capacities. Furthermore, the litter or dead organic matter is considered synonymously with carbon pool by the Inter-Governmental Panel on Climate Change. Thus, the highly differentiated, hierarchical soil structure with the ion exchange capacity and the acid buffering capacity are the main characteristics of forest soils, confounding the desired ecosystem services (Wilpert, 2022).

However, the functions of forest soils are vulnerable to several environmental and forest management activities: monoculture, soil compaction (machinery use) and soil acidification. It necessitates the urgent need for sustainable forest soil conservation to preserve their rich biodiversity, productivity and functionality. Soil and vegetation depend on and interact with each other one cannot flourish without another (Rwibasira*et al*., 2021). Among all other peculiarities of forest soil, its carbon sequestration potential is one of the globally demanding needs in this period of global warming and climate change.

Forest soils: Sequestering carbon to reach the goal of 4 per mille

At the Conference of Parties (COP) 21, the French Minister of Agriculture Stéphane Le Foll set an ambitious international research program, the ‘4 per mille Soils for Food Security and Climate’ of the Lima-Paris Action Agenda. The 4 per mille or 4 per 1000 aspires to increase global soil organic matter stocks by 0.4 per cent per year as a compensation for the global emissions of greenhouse gases by anthropogenic sources. It was launched during COP 21 in December 2015 and was supported by almost 150 signatories (countries, regions, international agencies, private sectors and NGOs). Stakeholders commit to a voluntary action plan to implement farming practices that maintain or enhance soil carbon stocks in agricultural lands and preserve carbon-rich soils (Chambers *et al*., 2016; Lal, 2016). The outcomes highlight region-specific efforts and scopes for soil carbon sequestration. But the role of forest soil in meeting the objective is less discussed among stakeholders.

Soil organic carbon (SOC) stock is a principal part of the global carbon cycle that involves carbon cycling through the soil, plants, ocean, and atmosphere (Shapkota and Kafle, 2021). Forest soils account for 86 % of the vegetation carbon pool and 73 % of the soil carbon pool, and it serves as a global carbon sink (Zhang *et al*., 2007). Global forest SOC stock was 580 Pg (Eswaran *et al*., 1993), and interestingly 60-70% of carbon in forests is stored as organic material in the soil (Janssens *et al*., 1999). Forest ecosystems fix two-thirds of the carbon in all terrestrial ecosystems annually. Moreover, forest ecosystems play an irreplaceable role in regulating the carbon balance, mitigating greenhouse gas concentrations, such as CO_2 and maintaining global climates (Zhang *et al*., 2009). SOC in Indian forests is 1.6-1.8 per cent of the carbon stored in the world's soils (23.4- 47.5 Pg C or 23.4-27.1 Gt) (Shukla *et al*., 2012).

Bhattacharyya *et al*. (2008) estimated that Indian soils contain only 9.55 and 24.04 Gt organic C (SOC) out of about 13.69 and 46.50 Gt of total carbon in the top 0.3 and 1 m soil, respectively. Sreenivas *et al*. (2016) estimated SOC of 22.72 ± 0.93 in the top 1 m. Similarly, using modelling approaches, Falloon *et al*. (2007) estimated C stock for Indian soils as about 6.5-8.5 Gt, whereas Banger *et al*. (2015) reported the stock at 20.5 to 23.4 Gt. Thus, the Indian contribution to the global SOC pool is around 20- 25 Gt for the top 1 m. Forests significantly contribute around 9.38 Gt to the total SOC stock with a high mean SOC density (139.9 t C ha^{-1}) (Sreenivas *et al*., 2016). Maji *et al*. (2010) suggest the requirement of immediate rehabilitation measures to improve SOC stock by considering the declining forest area and availability of 147 M ha of degraded land in India.

Increasing SOC; not only reduces greenhouse gas CO_2 in the atmosphere but also improves the soil structure. As a strategy for climate change mitigation, soil carbon sequestration buys time over the next ten to twenty years while other effective low carbon technologies become viable (Minasny*et al*., 2019).

Case studies

1) Quantification of organic carbon and primary nutrients in litter and soil in a foothill forest plantation of eastern Himalaya (Shukla *et al*., 2017)

The study analysed the amount of litterfall and its subsequent decomposition and quantified available nutrients and soil physicochemical characteristics in plantations of four forest tree species (*Lagerstroemia parviflora*, *Tectona grandis*, *Shorearobusta* and *Micheliachampaca*) in the Chilapatta Reserve Forest of the Cooch Behar Wildlife Division in the Terai zone of West Bengal, India. The amount of soil organic carbon was highest for *T. grandis* (2.52 Mg ha^{-1}) and lowest for *L. parviflora* (2.12 Mg ha^{-1}). Litter is the source of soil organic matter, and the more litter, the higher the content and amount of soil organic carbon in the plantations and forests.

2) Carbon Storage of Single Tree and Mixed Tree Dominant Species Stands in a Reserve Forest- Case Study of the Eastern Sub-Himalayan Region of India (Rai *et al*., 2021)

The study conducted at Jaldapara national park in the Eastern Himalayan region, India, quantified litter production, decomposition, periodic nutrient release, soil fertility status, and soil organic carbon (SOC) of five forest stands *Tectona grandis, Shorearobusta, Micheliachampaca, Lagerstroemia parviflora* and miscellaneous stand. SOC varies significantly under different forest stands, highest estimated on miscellaneous stands. In the study region, the SOC ranges between 75.9 and 107.7 Mg ha^{-1} up to 60 cm.

Conclusion and Recommendations

Understanding the long-term effects of tree species on soil properties is crucial for the development of forest restoration policies concerning the choice of species that meet both environmental and local livelihood needs. Soil C 4 per mille can make soils a sustainable resource, not a renewable resource. The best strategy is to restore the SOC content in degraded areas, as it offsets greenhouse gas emissions and provides benefits of enhanced soil conditions. Progress in 4 per mille requires collaboration and communication between scientists, farmers, policymakers, and marketeers. In addition, the initiative is an opportunity to implement a sound and credible soil carbon auditing protocol for monitoring, reporting, and verifying SOC sequestration, which can fit into national GHG inventory procedures (Chambers *et al*., 2016).

By considering the potential of forest soils in organic matter accumulation and storage as organic carbon, their conservation measures should be considered in local, regional and national level planning. Conserving forest soils with vegetation is a cost-effective strategy to make the 4 per mille vision come true.

References

Banger K, Tian H, Tao B, Lu C, Ren W and Yang J (2015) Magnitude, spatiotemporal patterns, and controls for soil organic carbon stocks in India during 1901–2010. *Soil Sci. Soc. Am. J.* **79:** 864-875.

Bhattacharyya T, Pal D K, Chandran P, Ray S K, Mandal C and Telpande B (2008) Soil carbon storage capacity as a tool to prioritize areas for carbon sequestration. *Curr. Sci.***95:** 482-484.

Boyle J R (2005) *Forest soils*, Elsevier ltd. Pp. 73

Burst M, Chauchard S, Dambrine E, Dupouey J L and Amiaud B (2020) Distribution of soil properties along forest-grassland interfaces: Influence of permanent environmental factors or land-use after-effects? *Agric. Ecosyst. Environ.***289:** 106739.

Chambers A, Lal R and Paustian K (2016) Soil carbon sequestration potential of US croplands and grasslands: implementing the 4 per thousand initiative. *J. Soil Water Conserv.***71:** 68A-74A.

Chapman S J, Bell J S, Campbell C D, Hudson G, Lilly A, Nolan A J, Robertson A H J, Potts J M and Towers W (2013) Comparison of soil carbon stocks in Scottish soils between 1978 and 2009. *Eur. J. Soil Sci.***64:** 455-465.

Eswaran H, Van Den Berg E and Reich P (1993) Organic Carbon in Soils of the World. *Soil Sci. Soc. Am. J.* **57:** 192-194.

Falloon P, Jones C D, Cerri C E, Al-Adamat R, Kamoni P, Bhattacharyya T, Easter M, Paustian K, Killian K, Coleman K and Milne E (2007) Climate change and its impact on soil and vegetation carbon storage in Kenya, Jordan, India and Brazil. *Agric. Ecosyst. Environ.***122:** 114-124.

Janssens I A, Sampson D A, Cermak J, Meiresonne L, Riguzzi F, Overloop S and Geulemans R (1999) Aboveground and belowground phytomass and carbon storage in a Belgian Scots pine stand. *Ann. For. Sci.***56:** 81-90.

Lal R (2008) Carbon sequestration. *Philo. Trans. Roy. Soc. B: Biol. Sci.***363(1492):** 815-830.

Lal R (2016) Beyond COP 21: potential and challenges of the “4 per Thousand” initiative. *J. Soil Water Conserv.***71:** 20A–25A.

Maji A K, Obi Reddy G P and Sarkar D (2010) *Degraded and Wastelands of India Status and Spatial Distribution*. Indian Council of Agricultural Research, New Delhi.

Makowski V, Julich S, Feger K H and Julich D (2020) Soil Phosphorus Translocation via Preferential Flow Pathways: A Comparison of Two Sites with Different Phosphorus Stocks. *Front. For. Glob. Chang.***3:** 48.

Minasny B, Malone B P, McBratney A B, Angers D A, Arrouays D, Chambers A, Chaplot V, Chen Z, Cheng K, Das B S, Field D J, Gimona A, Hedley C B, Hong S Y, Mandal B, Marchant B P, Martin M, McConkey B G, Mulder V L, O'Rourke S, Richer-de-Forges A C, Odeh I, Padarian J, Paustian K, Pan G, Poggio L, Savin I, Stolbovoy V, Stockmann U, Sulaeman Y, Tsui C, Vågen T, Wesemael B v and Winowiecki L (2017). Soil carbon 4 per mille. *Geoderma***292:** 59-86.

Rai P, Vineeta, Shukla G, Manohar K A, Bhat J A, Kumar A, Kumar M, Cabral-Pinto M and Chakravarty S (2021) Carbon Storage of Single Tree and Mixed Tree Dominant Species Stands in a Reserve Forest- Case Study of the Eastern Sub-Himalayan Region of India. *Land***10:** 435.

Rwibasira P, Naramabuye F X, Nsabimana D and Carnol M (2021) Long-Term Effects of Forest Plantation Species on Chemical Soil Properties in Southern Rwanda. *Soil Syst.***5:** 59.

Shapkota J and Kafle G (2021) Variation in Soil Organic Carbon under Different Forest Types in ShivapuriNagarjun National Park, Nepal. *Scientifica* 1382687.

Shukla G, Koul D N and Chakravarty S (2012) Soil Carbon Sequestration vis-à-vis Soil Management. *Environment & We an International Journal of Science and Technology***7:** 107-122.

Shukla G, Pala N A and Chakravarty S (2017) Quantification of organic carbon and primary nutrients in litter and soil in a foothill forest plantation of eastern Himalaya. *J. For. Res.*, DOI 10.1007/s11676-017-0394-7

Sokołowska J, Józefowska A, Wo´znica K and Zaleski T (2020) Succession from meadow to mature forest: Impacts on soil biological, chemical and physical properties- Evidence from the Pieniny Mountains, Poland. *Catena***189:** 104503.

Sreenivas K, Dadhwal V K, Kumar S, Harsha G S, Mitran T, Sujatha G, Suresh G J R, Fyzee M A and Ravisankar T (2016) Digital mapping of soil organic and inorganic carbon status in India. *Geoderma***269:** 160-173.

Takahashi M (2021) Nutrient Storage and Stoichiometry of the Forest Floor Organic Matter in Japanese Forests. *Soil Syst.***5:** 51.

Weil R R and Brady N C (2017) *Nature and Properties of Soils*, Pearson, London, UK.

Wilpert K v (2022) Forest Soils- What’s Their Peculiarity? *Soil Syst.***6:** 5.

Zhang N, Yu Z L, Yu G R and Wu J (2007) Scaling up ecosystem productivity from patch to landscape: a case study of the Changbai Mountain Nature Reserve, China. *Landscape Ecol.***22:** 303-315.

Zhang N, Zhao Y S and Yu G R (2009) Simulated annual carbon fluxes of grassland ecosystems in extremely arid conditions. *Ecol. Res.***24:** 185-206.

Management of Soil Biological Health

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Soil health is a critical factor in preserving important soil functions as well as agricultural and environmental sustainability and its maintenance has emerged a global priority in recent years. Soil biochemical reactions and processes,play important roles in soil health and plant growth. Understanding and managing soil biological health has, arisen as a critical problem for realizing the soil resource's potential for long-term crop production.It is well known that a large number of organisms live in soil and requires congenial environment for their growth, multiplication and functions and get affected by changes in soil environment, which in turn modify the soil biological properties and health. Followings are some of the advisable soil and crop management options, which may help in improving the soil biological health and functions.

Conservation Tillage

Labile organic reserves in soil generally decrease with cultivation and cropping and therefore, microbial biomass and microbial activities have been found more in undisturbed soilsthus, increase number of microorganisms, microbial biomass C and N and activities of soil enzymes (Mangalassery *et al*., 2015). In NE India, Rao *et al.* (2013) recorded higher MBC, dehydrogenase activity and earthworm population on rice-wheat/mustard/linseed sequence following zero tillage, double no-till and minimum tillage practices

Crop Rotations and Intercropping

Cropping systems influence the microbial biomass and soil productivity depending upon rotation length, inter and/or substitute crops, fallow duration and fertilization. Soil under continuous cropping has higher biomass C and N than soil under fallow and cropping + fallow due to variations in amount and composition of root exudates (Chandra, 2011).

Organic Manures and Crop Residues Application

Manures and plant residues have a major role in maintaining SOM content. Soil microorganisms grow rapidly during early phases of decomposition of plant residues and consequently some of the available soil nutrients, particularly N, P and S get immobilized in the microbial biomass. Immediately after incorporation into the soil plant materials are subjected to the transformation and decomposition processes of the heterotrophic microflora, and as a result, the population of bacteria fungi and actinomycetes increased with application of plant residues and FYM. The effect of organic manure or crop residue application on microbial community depends mainly on the biochemical composition of the applied organic materials

Green Manuring

Biomass and N accumulation in green manure legumes are influenced by species grown, water regime, nutrient supply, soil type, photoperiod, inoculation, and age of green manure. Basak *et al* (2017)reported that soil biological health indices such as soil MBC, microbial quotient and activities of soil enzymes like acid and alkaline phosphatase and aryl sulphatase were superior with IPNS with GM as compared to IPNS with FYM after 12 years of cultivation of rice–rape- sesame cropping sequence in an Inceptisol; shows a beneficial effect of continued green manuring on soil biological quality

Integrated Nutrient Management

Balanced and integrated use of plant nutrients promotes the soil microbial counts and various soil biological properties. Results of the long-term experiment conducted with the application of N and P fertilizers did not show significant increase in the organic C content of soil but the total N, microbial biomass C and N increased significantly. In a long-term study on rice-wheat rotation in Mollisols, Bhatt *et al*. (2016) noticed that integrated use of 100% NPK with 15 t FYM ha^{-1} sustained the crop yields and soil microbial population, MBC, CO_2 evolution and activities of enzymes dehydrogenase, acid and alkaline phosphatase, aryl-sulphatase and urease at higher level. Building up POM and microbial biomass would require addition of crop residues and chemical fertilizers in a balanced form. Chandra *et al.* (2008)noticed the highest population of soil microorganisms, biomass carbon and dehydrogenase enzyme activity in rhizosphere of sugarcane and wheat fertilized with recommended NPK and residue incorporation as sugarcane trash or *Sesbania* green manure.

Pest Management

Pest and diseases decrease the return of organic matter in to soil through reduction in biomass production, thus reducing the availability of the substrate for soil organisms. Srinivasulu et el. (2012) found that population of *Azospirillum*sp. and the rate of ammonification increased at particular concentrations of pesticides (i.e., 2.5 to 5.0 kg ha^{-1}) due to the synergistic interactions between pesticides and microorganisms, but at higher concentrations (7.5 and 10.0 kg ha^{-1}) the pesticides exerted antagonistic interactions. The effect of pesticides also varied with soil types.

Microbial Inoculation

The application of inoculants of soil beneficial organisms, such as nitrogen-fixing bacteria, phosphate solubilizing microorganisms (PSM), blue green algae and Mycorrhiza is recommended to minimize the use of chemical fertilizers. (Sharma *et al*., 2013)

Organic Farming

Organic farming system of crop production attempts the maintenance of soil fertility and the control of pests and diseases by the enhancement of natural process and biological cycles. In general, organically managed soils support higher biodiversity and microbial population compared to chemical/conventional farming system.

Soil Amendments

Soil organisms require some specific soil conditions for their growth and functioning. Most bacteria and actinomycetes prefer neutral soil pH, while slightly acidic soil conditions are optimum for the growth of fungi. Microbial growth and activity are affected adversely under conditions of drought, soil acidity and sodicity. Onwonga*et el*. (2010) examined the effect of different acid soil management practices such as liming (L), combined N and P fertilizers (NP), and goat manure (M) application for maize production. Application of LMNP and MNP treatments enhanced mineral N, MBC and MBN suggesting that conjoint use of manure, lime and NP fertilizers and /or manure and NP fertilizers as most promising alternative for sustainable acid soil management.

Epilogue

The significance of soil organisms in maintenance of soil health and crop production is well recognized. Available scientific literature indicates the loss in soil biodiversity and its functioning in different agricultural systems, but little efforts have been made for the management of soil biological diversity in farmer’s fields. This suggested the identification of best cropping system options for different agro-ecological situations taking account of climate, market availability and socio-economic status of farmers. There is need to study and establish the linkage between different soil organisms and their species on soil processes, functions and productivity under different agricultural systems. Further, there is need to develop simple biological index for soil quality/fertility evaluation based on various soil biological properties such as SOC, MBC, biomass C/N ratio, biochemical quotients, respiration rate, soil enzymes etc. Research is needed to understand the basic ecology of soil organisms in bulk soil as well as in close proximity to plant roots and seeds.

References:

Basak, N., Mandal, B., Datta, A., Mitran, T., Biswas, S., Dhar, D., Badole, S., Saha, B. and Hazra, G.C., 2017. Impact of long-term application of organics, biological, and inorganic fertilizers on microbial activities in rice-based cropping system. *Communications in Soil Science and Plant Analysis*, *48*(20), pp.2390-2401.

Bhatt, B., Chandra, R., Ram, S. and Pareek, N., 2016. Long-term effects of fertilization and manuring on productivity and soil biological properties under rice (Oryza sativa)–wheat (*Triticum aestivum*) sequence in Mollisols. *Archives of Agronomy and Soil Science*, *62*(8), pp.1109-1122.

Chandra, R. (2011) Effect of summer crops and their residue management on yield of succeeding wheat and soil properties.*Journal of the Indian Society of Soil Science***59,** (1):37-42.

Chandra, R., Rana, N.S., Kumar, S. and Panwar, G.S., 2008. Effects of sugarcane residue and green manure practices in sugarcane-ratoon-wheat sequence on productivity, soil fertility and soil biological properties. *Archives of Agronomy and Soil Science*, *54*(6), pp.651-664.

Mangalassery, S., Mooney, S.J., Sparkes, D.L., Fraser, W.T. and Sjögersten, S., 2015. impacts of zero tillage on soil enzyme activities, microbial characteristics and organic matter functional chemistry in temperate soils. *European Journal of Soil Biology*, *68*, pp.9-17.

Onwonga, R.N., Lelei, J.J. and Mochoge, B.B., 2010. Mineral nitrogen and microbial biomass dynamics under different acid soil management practices for maize production. *Journal of Agricultural Science*, *2*(1), p.16.

Rao, D.L.N., 2013. Soil biological health and its management. *Soil health management: productivity-sustainability-resource management. FDCO, New Delhi*, pp.55-83.

Sharma, S.B., Sayyed, R.Z., Trivedi, M.H. and Gobi, T.A., 2013. Phosphate solubilizing microbes: sustainable approach for managing phosphorus deficiency in agricultural soils. *SpringerPlus*, *2*(1), pp.1-14.

Srinivasulu, M., Mohiddin, G.J., Madakka, M. and Rangaswamy, V., 2012. Effect of pesticides on the population of Azospirillum sp. and on ammonification rate in two soils planted to groundnut(*Arachis hypogaea* L.). *Tropical Ecology*, *53*(1), pp.93-104.

Biofertilizer Technologies or Enhancing Nutrient Use Efficiency in Rice

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1. Introduction

The persistent use of chemical fertilizers, especially urea, along with chemical pesticides and unavailability of organic manures has led to reduced implication on soil health and failing sustainability of the agricultur**e** systems (Kumar *et al*., 2018). Therefore, a wider range of improving strategies would be required to meet up the challenges of enhancing crop productivity including rice. Beneficial microorganisms are one of the best options to overcome this situation, by exploring their potentiality mostly unique properties of tolerance to extremities, ubiquity, genetic diversity, and their interaction with crop plants for sustainable rice production. Presently, biofertilizers have emerged as a highly potent alternative to chemical fertilizers due to their eco-friendly, easy to apply, non-toxic and cost-effective nature. Thus, biofertilizers represent a new technology for agriculture that promises to balance many of the shortcomings of the conventional chemical-based technology. Biofertilizers are products that are likely to be commercially promising in the long run once adequate information becomes available to producers and farmers. However, data revealed that more than 50% production of biofertilizers is localized on southern part of Indian states and only 2% is produced by eastern states including Odisha (0.8%) which may not fulfil the requirement of farming community. Moreover, farmers of Odisha also are not using biofertilizers due to lack of knowledge and awareness about its benefit. Recently, ICAR-National Rice Research Institute (NRRI), Cuttack (Odisha) has received grant of Rs. 284.36 Lakhs from RKVY, Odisha to construct model biofertilizer units exclusively for mass production and supply of quality biofertilizers especially nitrogen fixing, phosphate solubilizing and mobilizing microbial inoculates based on nutrient requirements of rice crops, which can reduce the nitrogen and phosphorous requirement by 20 and 25%, respectively without declining the crop yield. Additionally, one of the objectives of this project is to conduct training to make aware of benefit use of biofertilizers to different stakeholders of farming community of Odisha. In the present chapter, NRRI-developed rice-specific microbial technologies have been highlighted and these technologies may serve as a potential measure in suppression of some of the major global problems related with the sustainability of rice crop.

2. Microbial technologies

2.1 Biofertilizers

Biofertilizers means the product containing carrier based (solid or liquid) living microorganisms which are agriculturally useful in terms of nitrogen fixation, phosphorus solubilization or nutrient mobilization, to increase the productivity of the soil and/or crop plants. Presently, biofertilizers have emerged as a highly potent alternative to chemical fertilizers because of their eco-friendly, easy to apply, non-toxic and cost effective nature. In addition, biofertilizers are one of the promising technologies for rice productions, however, it is not popular among farming community particularly rice growers all over India, due to lack of knowledge and awareness of its use in an effective way. Moreover, government has taken many steps to improve use of application of biofertilizers in agriculture. Its regular application keeps soil biologically active and preserving soil health. The recommendation of bio-fertilizers for rice crop is given in Table 1.

Table1. Recommendation of bio-fertilizers for rice crop

Inoculants	**Recommendations**	**Nutrients supply to plants**	**Increase of grain yield**
Blue green algae	50-60 kg fresh wt/ha (or) 6-7 kg dry weight	20-25 kg /ha/season	10-20%
Azolla	10-15 t fresh wt/ha	20-40 kgN/ ha/ 20-75 days	10-30%
Azospirillum	5-6 kg solid/ 500 ml liquid/ ha	5-10 kg N/ha	5-15%
Azotobacter	5-6 kg solid/ 500 ml liquid/ ha	5-10 kg N/ha	5-15%
AM fungi	1 ton soil based inoculums/ha (Upland rice)	Supplemented 30% Phosphorus	15-25% (upland rice with crop rotation)
PSB	5-6 kg solid/ 500 ml liquid/ ha	Supplemented 10-20% Phosphorus	5-15% (upland rice)

2.2. Blue green algae (BGA) used as Bio-fertilizer in rice cultivation

Efficient nitrogen fixing strain like *Nostoclinkia, Anabaena variabilis, Aulosirafertilisima, Calothrix* sp*., Tolypothrix*sp*., and Scytonema*sp. were identified from various agro-ecological regions and utilized for rice production. Cyanobacteria play an important role in maintenance and build-up of soil fertility, consequently increasing rice growth and yield as a natural bio-fertilizer. They have potentiality to fix large amount of atmospheric nitrogen (up to 20 - 25 kg/ha). Genera *Nostoc, Anabaena, Tolypothrix*and *Aulosira*are used as inoculants for paddy crop grown both under upland and low land conditions. Cyanobacteria play following important role in maintenance and buildup of soil fertility, consequently increasing rice growth and yield as a natural bio-fertilizer:

- Diazotrophic cyanobacteria maintain and increase the soil fertility of rice fields.
- Reduce the nitrogenous consumption by 15-30 percent (20-30 kg N/h/season).
- Increase productivity of rice by 10-15%.
- Algalization induces early grain setting and maturity.
- Checks weeds proliferation by blocking nutrient supply and light.
- Increase the utilization of N-fertilizer by partially reducing the losses through run-off, leaching and denitrification.
- Buffers the soil against rapid changes in pH.
- Reported to reduce the salinity in the soil leading to better crop response.
- Enhance the activity of other beneficial micro-flora and increases population.
- Protection of plants from pathogenic insects and diseases as bio-control agents.
- Mineralization of simpler organic molecules such as amino acids for direct uptake.
- Increase in soil pores with having filamentous structure and production of adhesive substances.
- Increase in soil biomass after their death and decomposition.

2.3. *Azolla* for soil health improvement

Azolla technology is widely accepted throughout the world as efficient nitrogen contributor in rice ecology through symbiotically associated cyanobacteria with them (Kumar *et al*., 2019a).Sporulation and sexual reproduction of *Azolla* are essential for the survival of the associations under adverse environmental conditions, such as tropical /sub-tropical summers and temperate zone winters. Field observations and laboratory studies indicate that sporulation in *Azolla* species is not simply a seasonal phenomenon linked to photoperiod. Rather, sporulation appears to be induced by the interacting effects of environmental factors, including temperature, light intensity, nutrients, and plant density. Furthermore, the conditions leading to the induction of sporulation are not the same for all species (Kumar and Nayak 2019; Kumar *et al*., 2019a; Kumar *et al*., 2021b).

As regards to the biomass production, and quantity of nitrogen fixation and nutrient recycling, *Azolla* is highly efficient, cost-effective and ecologically sound bio-fertilizer. To produce *Azolla* inoculum in paddy fields, its vegetative fronds in large scale are required but there are several physical constraints in *Azolla* production and utilization. The thick wall of megasporocarp can withstand high temperature, drought condition, and pest attack. Most of the researchers have documented the sporocarp production of *Azolla* only from a limited number of species but it has to be studied thoroughly with 102 strains available at NRRI germplasm collections (Kumar *et al*., 2018c; 2021a).

2.4. Arbuscular mycorrhizal fungi (AMF) in rice

AMF colonization in rice plant has been documented by many researchers and this fungal association in rice found to enhancing P acquisition. At NRRI Cuttack**,** AMF association was studied in 72 different rice cultivars including two low P tolerant checks *viz*., Kasalath and Dular, which were raised in P deficient soil (< 6.0 – 8.0 ppm). The AM fungal root colonization was recorded in the range of 20 - 90 %, whereas, it was 80 - 90 % in Kasalath and Dular cultivars. These two varieties have the dominant unique type of vesicle-forming AMF colonization, which was not observed in many low P tolerant varieties. This observation clearly indicates that some genera of AM fungi may prefer the specific rice genotype of rice. It is well-known fact that Kasalath and Dular possess the protein kinase gene *pstol* for phosphorus-deficiency tolerance, thus these varieties having a unique kind of AM root colonization in P deficient soil.

3. Microbial products/ formulations developed at NRRI, Cuttack

The following microbial technologies especially for rice crop are available at NRRI, Cuttack (Fig. 1):

- Rice-specific liquid bioinoculant of endophytic nitrogen fixing *Azotobacter chrococcum* strain AVi2 (MCC no. 3432; KP099933) and rhizospheric *Azotobacter vinelandii*strain SRIAz3 (JQ796077) for nitrogen management in rice under sub-tropical condition which could replace ~ 25% of chemical nitrogen without compromising yield (Kumar *et al*., 2019b, 2021b, c).
- Sporocarp-based formulations to be to reduce the initial inoculums load of *Azolla* in paddy field, also have attempted on induction of sporocarp in different species of *Azolla* and found that some strains of *Azolla* are strongly sensitive to the environment and sporulate only during winter months (November-March) (Kumar *et al*., 2021d).
- Arka Microbial consortium and Actino plus package have been standardized for low-land and aerobic rice production systems
- Phosphate solubilizing and exopolysachharide producing liquid bacterial bioinoculants for management of phosphorous problem and alleviating drought in rice, respectively.

- *Azolla* based microbial medium and *Azolla* pellets for livestock feed: *Azolla* potentials other than biofertilizer like livestock feed, microbial growth medium has been developed (Kumar *et al.*, 2021e).

Fig. 1 Microbial bioinoculants especially for rice crop are available at NRRI, Cuttack

4. Setting up bio-fertilizers production unit, cost involvement and entrepreneurship opportunities

Type of Bio-fertilizers	**Production capacity**	**Area requirement/ others**	**Instrument and operational cost**	**Total cost (Rs in lakh)**	**Gain in Rs (lakh)**
Bacterial-based	50 t / year	1200 sq feet (building cost with site) Cost: 24.0 lakh	Instruments 41.0 lakhs Operational cost : 17.0 lakhs	82.96 lakhs	If we sell Rs. 100 per kg 51.0 lakhs per year

AM fungal fertilizers	5 t/ harvest (2months/ cycle) 30 t/ year	40 ft x 3 x 1.5 ft) with fencing Cost : 2.0 lakh	Operational cost : 5.0 lakhs	7.0 lakhs	If we sell Rs. 50 per / kg 15 lakhs per year
BGA	500 kg per harvest 10 t/ year	500 m^2 area (cost): 2.0 lakh	Operational cost : 2.0 lakhs	4.0 lakhs	If we sell Rs. 50 per / kg 5.0 lakhs per year
Azolla	500 kg per harvest 10 t/ year	500 m^2 area (cost): 2.0 lakh	Operational cost : 2.0 lakhs	4.0 lakhs	If we sell Rs. 50 per / kg 5.0 lakhs per year

5. Conclusion and way forward

Climatic intervention decreases the rice productivity; hence, there is an urgent need to develop advance and innovative microbial technology for management of these stresses. Beneficial microbes present in soil and plant have huge potentials to alleviate the stresses. Overall, the present chapter describes the different scenario of harnessing microbial resources for soil health management. The following microbe-mediated works are essentially needed in future for sustainable development of rice crop particularly in eastern India.

- Microbial consortia especially for rice crop are to be developed for soil health management.
- Molecular markers to be identified through meta- and transcriptome sequence of *Azolla* for better understanding of *Azolla*-cyanobiont interactions for sustainable production of rice.
- Latest molecular tools must be explored to understand the soil biological nutrient cycling in paddy soil.

References

Kumar U, Nayak AK, Shahid M, Gupta VVSR, Panneerselvam P, MohantyS, Kaviraj M, KumarA, Chatterjee D, LalB, Gautam P, TripathiR, Panda BB. (2018).Continuous application of inorganic and organic fertilizers over 47 years in paddy soil alters the bacterial community structure and its influence on rice production. *Agriculture Ecosystems & Environment*. 262:65-75.

Kumar U and Nayak AK. (2019). Azolla Germplasms at NRRI: Conservation, Characterization and Utilization *NRRI Research Bulletin No. 19.* ICAR-NRRI, Cuttack. 68.

Kumar U, Nayak AK, Panneerselvam P, Kumar A, Mohanty S, Shahid M, Sahoo A, Kaviraj M, Priya H, Jambhulkar NN, Dash PK. (2019a). Cyanobiont diversity in six *Azolla* spp. and relation to *Azolla*-nutrient profiling. *Planta*.1-3. https://doi.org/10.1007/s00425-019-03093-7

Kumar U, Kaviraj M, Panneerselvam P, Priya H, Chakraborty K, Swain P, Chatterjee SN, Sharma SG, Nayak PK and Nayak AK. (2019b). Ascorbic acid formulation for survivability and diazotrophic efficacy of Azotobacter chroococcum Avi2 (MCC 3432) under hydrogen peroxide stress and its role in plant-growth promotion in rice (*Oryza sativa* L.). *Plant Physiology and Biochemistry*, 139: 419-427.

Kumar U, Nayak AK, Sahoo S, Kumar A, Kaviraj M, Shahid M. (2020). Combined effects of elevated CO_2, N fertilizer and water deficit stress on diazotrophic community in sub-humid tropical paddy soil. *Applied Soil Ecology*. 155: 1-12.

Kumar U, Kaviraj M, Rout S, Chakraborty K, Swain P, Nayak PK, Nayak AK. (2021a). Combined application of ascorbic acid and endophytic N-fixing *Azotobacter chroococcum* Avi2 modulates photosynthetic efficacy, antioxidants and growth-promotion in rice under moisture deficit stress. *Microbiological Research*. 250:126808.

Kumar U, Rout S, Kaviraj M, Swain P, Nayak AK. (2021b). Uncovering morphological and physiological markers to distinguish *Azolla* strains. *Brazilian Journal of Botany*.https://doi.org/10.1007/s40415-021-00725-9

Kumar U, Kaviraj M, Dangar TK, Panneerselvam P, Nayak AK. (2021c). Liquid Bioinoculant of Endophytic (*Azotobacter chroococcum*) and Rhizospheric (*Azotobacter vinelandii*) Nitrogen Fixing Bacteria for Rice Crop. NRRI Technology Bulletin no. 158. ICAR-NRRI, Cuttack.

Kumar U, Kaviraj M, Rout S, Pannereselvam P, Nayak AK. (2021d. NRRI Azolla-sporocarp formulation for nitrogen management in low land rice. TechNRRI. NRRI Technology Bulletin 157. ICAR-NRRI, Cuttack.

Kumar U, Kaviraj M, Pannereselvam P, Nayak AK. (2021e). NRRIAzo-Media (NAM): A microbial growth culture media. Tech NRRI. NRRI Research/Technical Brief 06. ICAR-NRRI, Cuttack.

Bio-Priming and Bioaugmentation: A Potential Strategy for Safeguarding the Fragile Ecosystem of the Indo-Gangetic Plains

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Managing agrochemicals for crop production always remains a classic challenge for us to maintain the doctrine of sustainability. Intensively cultivated rice-wheat production system without using the organics (organic amendments, manures, biofertilizers) has a tremendous impact on soil characteristics (physical, chemical, and biological), environmental quality (water, air), input use efficiency, ecosystem biodiversity, and nutritional security. Consequently, crop productivity is found to be either decreasing or stagnating. Rice-wheat cropping system is the major agroecosystem in India feeding millions of people, which is widely practiced in the *Indo-Gangetic Plains* (IGP). Microorganisms as key players in the soil system can restore the degraded ecosystems using a variety of mechanisms. Here, we propose how delivery systems (i.e., the introduction of microbes in seed, soil, and crop through bio-priming and/or bioaugmentation) can help us in eradicating food scarcity and maintaining sustainability without compromising the ecosystem services. Both bio-priming and bioaugmentation are efficient techniques to utilize bio-agents judiciously for successful crop production by enhancing phytohormones, nutrition status, and stress tolerance levels in plants (including mitigating of abiotic stresses and biocontrol of pests/pathogens). However, there are some differences in application methods, and the latter one also includes the aspects of bioremediation or soil detoxification. Overall, we have highlighted different perspectives on applying biological solutions in the IGP to sustain the dominant (rice-wheat) cropping sequence.

Micronutrient Biofortification: Substance Beneath the Sparkle

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The need for micronutrient research in developing countries like India and its consequent effect on the diet-based nutrition of a giant diaspora is still undermined to a greater extent. Micronutrient interventions undoubtedly have a very significant, positive impact on morbidity, mortality and health, especially for women, infants, and children. However, substantial gaps in our knowledge remain such that current intervention policies are probably not optimal. We need to take advantage of more modern technologies and approaches in nutrition science to expand our knowledge about the effects of micronutrient management strategies on plant nutrition and human health. Flawed food systems were designed to feed the ever-growing populace and were never meant to improve human nutrition and health, which forms the very basis of malnutrition among people *esp*. children and women in resource-poor geographic locales of the country. Undeniably, all food systems are directly dependent on prevalent agricultural systems which are the primary source of nutrients entering the daily diet of humans. Large numbers of people in developing countries exist on simple diets composed primarily of a few staple foods that are mostly poor sources of some macronutrients and many essential micronutrients. Strategies to regulate/ manipulate the nutritional composition of food grains is an urgent issue as basic nutritional requirements of much of the world’s population are still quite superficial. Thus, the agricultural scenario plays the fundamental role in human nutrition and even a minor overlook may lead to the development of malnutrition on a global scale. If the products obtained from farming systems cannot provide essential nutrients required for sustaining human life, malnutrition ensues, causing a leap in morbidity or mortality rates and stagnation in development of populations which have major dependence on these systems (Bouis *et al*., 2012). Since agricultural products are invariably the primary source of all nutrients essential for human body development, effective agricultural practices and policies have the innate potential to thwart malnutrition.

Both plants and humans require micronutrients for their healthy growth and development. In general, these micronutrients like all other mineral nutrients in the soil are taken up by the plant roots and transported to the edible parts for human consumption passing through a rather complex translocation pathway which involves different transporters. Due to the great difference in the concentration of micronutrients required by plants and humans, it is a challenge to balance plant growth and nutrient requirement for humans.

Several unforeseen consequences of the ‘green revolution’ include a shift from more diverse traditional cropping systems to cereal production systems thus resulting in less bioavailable micronutrient and a rapid rise in micronutrient malnutrition in economically benighted families mostly dependent on these agricultural systems for sustenance (Welch and Graham, 1999). Reportedly, these traditional crops were much more micronutrient-dense in comparison to the high yielding cereals that displaced them (National Research Council, 1996).

The soil-plant continuum is instrumental to human nutrition and forms the basis of micronutrient cycling, thus resulting in an ecologically benign and sustainable flow of micronutrients (Yang *et al*., 2007). Soil-plant system strategies for enhanced micronutrient bioavailability supplementing human nutrition mainly include the exploitation of micronutrient-dense crop genotypes (for genetic manipulation); isolation of efficient rhizobacteria with micronutrient solubilizing capabilities; developing a better knowhow regarding the mechanisms of micronutrient translocation or the associated barriers; establishing the relationship between the content and bioavailability of micronutrients in soils and those in edible crop products for better human nutrition; and developing and/or identifying effective micronutrient sources with proper dose and mode of application for incorporation into integrated nutrient management modules.

We need to acknowledge the fact that fertilization or supply mechanism is not an alternative for the otherwise effective plant breeding or transgenic approach of biofortification, but is more of a complementary and synergistic move. Uniform combination of these tools can create a synergistic impact on the overall accumulation of micronutrients in seeds at desirable amounts for human nutrition evading the adverse effect of anti-nutritional factors. Thus, future micronutrient research should lay major emphasis on consumption considerations rather than just the crop health while implementing sustainable strategies for the development of functional food through potent biofortification techniques.

References

Bouis, H., Gallego, E.B. and Meenakshi, J.V. (2012). Micronutrient malnutrition: Causes, prevalence, consequences and interventions. p. 29-64. Fertilizing Crops to Improve Human Heath: A Scientific Review. Vol. 1, Food and Nutrition Security. IPNI; IFA, Norcross, GA, USA; Paris, France.

National Research Council. (1996). Lost Crops of Africa. Grains, National Academy Press, Washington, D.C. **1**:1- 383.

Welch, R.M. and Graham, R.D. (1999). A new paradigm for world agriculture: meeting human needs—productive, sustainable, nutritious. *Field Crops Research*. **60**:1–10.

Yang, J.Y., He, Z.L., Yang, Y.G. and Stoffella, P.J. (2007). Use of soil amendments to reduce leaching of nitrogen and other nutrients in sandy soil of Florida. *Soil and Crop Science Society of Florida Proceedings*. **66**:49-57.

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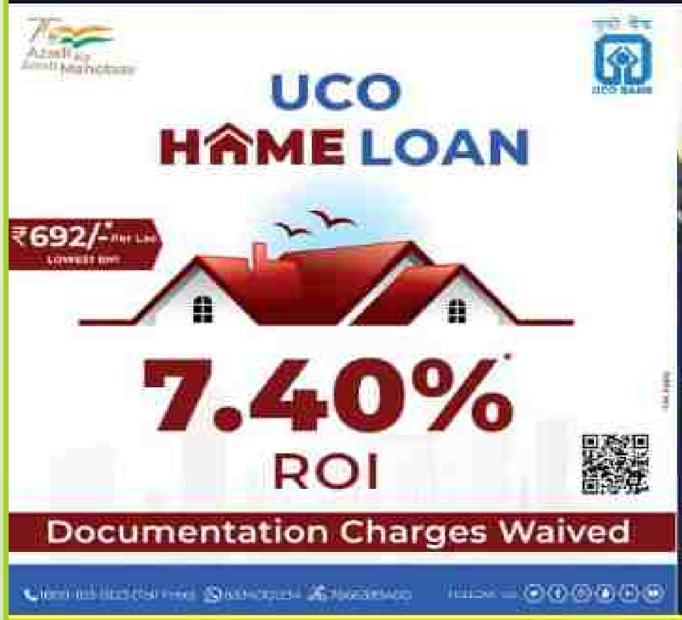

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