23rd

Annual Convention and National Conference

Application of Clay and Allied Sciences in Agriculture, Environment and Industry

22-23 December 2021

ICAR-IARI, New Delhi

ABSTRACTS BOOK

Organised by

The Clay Minerals Society of India, New Delhi

In collaboration with

Division of Soil Science and Agricultural Chemistry
ICAR-IARI, New Delhi

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Annual Convention and National Conference

*Application of Clay and Allied Sciences
in Agriculture, Environment and Industry*

December 22-23, 2021

**ICAR-Indian Agricultural Research Institute
New Delhi**

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The Clay Minerals Society of India

(Regd., Estd.1981)
Division of Soil Science and Agricultural Chemistry
ICAR-Indian Agricultural Research Institute, New Delhi

President
Dr. Samar Chandra Datta
FCMSI, FISSS
9891119948(M)

Message

   The Clay Minerals Society of India (CMSI) is organizing its 23rd Annual Convention and National Conference on "Application of Clay and Allied Sciences in Agriculture, Environment and Industry" in collaboration with Division of Soil Science and Agricultural Chemistry, ICAR-IARI, New Delhi during December 22-23, 2021 at ICAR – Indian Agricultural Research Institute in hybrid mode (online and offline mode). The CMSI is a premier interdisciplinary and professional society founded in 1981 and registered in 1982 to serve as a nerve centre for Scientists, Industrialists, Technologists and others engaged in the advancement of science in the field of application of clay. Clay, the precious gift of nature is the most important reactive component of soil due to its electric charge, high specific surface area and high aspect ratio. It governs the buffering, filtering and nutrient supplying capacity of soils. It helps in sequestering carbon by making complex with humus in the soil and protects environment from global warming.

   Clay has its immense scope in developing value-added product such as efficient fertilizer carriers, efficient plant protection formulations, modified clay to remediate heavy metal pollution in soil and water and other industrial products like pharmaceuticals, ceramics and petrochemicals. I hope two days deliberation will be very helpful in shaping the roadmap of clay research as well as in motivating young researchers to take up the work on various aspects of clay. Our society bestows Student Award for research in clay science. I wish all a great success in this deliberation. I take this opportunity to extend my sincere thanks to the organizing committee members for active cooperation and support extended to me for organizing the conference.

Dated: 20.12.2021   (S.C. Datta)
Place: New Delhi

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December 22-23, 2021

Venue: ICAR-Indian Agricultural Research Institute, New Delhi

Programme

Day-1: December 22, 2021 (Wednesday)

11.00   Inaugural Session

12.30-13.15   Special Lecture
               Chairperson: Prof. S.K. Ghosh, Former Professor & Head, Division of Soil Science and Agricultural Chemistry, ICAR-IARI, New Delhi
               Speaker: Dr. S.K. Sanyal, Former VC, BCKV, Mohanpur, West Bengal
               Rapporteur: Dr. Sunanda Biswas, Scientist, Division of Soil Science and Agricultural Chemistry, ICAR-IARI, New Delhi
               Topic: Arsenic contamination of groundwater in parts of West Bengal (India): build-up in soil-crop systems & mitigation

13.15-14.00   Lunch

14.00-15.30   Best Ph.D. Thesis Presentation Award Contest

15.30-16.00   Tea

16.00-17.30   Annual General Body Meeting (AGM) of the CMSI

Day-2: December 23, 2021 (Thursday)

10.30 - 13.00 **Technical Session- I (Oral Presentations)**

               Chairperson: Dr. S.K. Ray, Principal Scientist, Head, ICAR-NBSSLUP Regional Centre Kolkata, West Bengal

               Rapporteur: Dr. Debarup Das, Scientist, Division of Soil Science and Agricultural Chemistry, ICAR-IARI, New Delhi

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2. **M. Chandrakala[1], R. Srinivasan[1], Anil Kumar K.S.[1], Sunil P. Maske[1], Rajendra Hegde[1] and B.S. Dwivedi[2]**
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[1]National Bureau of Soil Survey and Land Use Planning, Hebbal, Karnataka, India
[2]National Bureau of Soil Survey and Land Use Planning, Nagpur, Maharashtra, India

3. **Deepak Kumar, Ruma Das, S.P. Datta, Debasis Golui, Nayan Ahmed and Shrila Das**
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Influence of Clay distribution and Slope position on Mango colour and Yield in South-Eastern Ghat (SEG) of India
[1]ICAR-National Bureau of Soil Survey and Land Use Planning, Hebbal, Karnataka, India
[2]ICAR-National Bureau of Soil Survey and Land Use Planning, Nagpur, Maharashtra, India
[3]ICAR - Indian Institute of Horticultural Research, Hessaraghatta Lake Post, Bengaluru, Karnataka, India

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15. **Indu Chopra, Ann Theresa Jose, Manindra Barman and Kapil A. Chobhe**
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13.00-14.00   Lunch

14.00-15.30   **Technical Session- II (Oral Presentations)**

Chairperson: Dr. Nayan Ahmed, Principal Scientist, Division of Soil Science and Agricultural Chemistry, ICAR-IARI, New Delhi

Rapporteur: Dr. Prasenjit Ray, Scientist, Division of Soil Science and Agricultural Chemistry, ICAR-IARI, New Delhi

16. **Dibyendu Chatterjee[1,4], Sudip Kumar Dutta[2], Z. James Kikon[1], Rukuosietuo Kuotsu[1], Dibyendu Sarkar[3], B.S. Satapathy[4], Bidyut C. Deka[1], Abhijit Pradhan[4] and Saikat Ranjan Das[4]**
Characterization of non-conventional vermicomposts and their application for enhancing yield and quality of bell pepper
[1]ICAR-Research Complex for North Eastern Hill Region, Nagaland Centre, Jharnapani, Medziphema, Nagaland, India
[2]ICAR-Research Complex for NEH Region, Sikkim Centre, Tadong, Sikkim, India
[3]Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India
[4]ICAR-National Rice Research Institute, Cuttack, Odisha, India

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20. **Partha Sarathi Ghorai, Sunanda Biswas, T.J. Purakayastha, N. Ahmed, Priya Singh and Sujit Das**
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21. **Dhinu Yadav[1], Abir Dey[1] and Leela Wati[2]**

Tillage and residue management effect on soil properties and crop productivity under different cropping pattern in Haryana
[1]Division of Soil Sciences and Agricultural Chemistry, ICAR-Indian Agricultural Research Institute, New Delhi
[2]Department of Microbiology, CCS HAU, Hisar, Haryana

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23. **A.K. Dash, B.S. Dwivedi, M.C. Meena, Abir Dey, D. Chakraborty**
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Effect of engineered biochar on nutrient retention in an Inceptisol
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Effect of oil pollution on soil health
Geological Survey of India, Kolkata, West Bengal, India

26. **Prasenjit Ray, A. Das, B. Mhalla and Nayan Ahmed**
Characterization of soil acidity under hilly terrain of the Northwestern Himalayan Region of India
Division of Soil Science and Agricultural Chemistry, ICAR-Indian Agricultural Research Institute, New Delhi, India

15.30-16.00 Tea

16.00-17.00 **Plenary Session**
Panelists: Dr. Kunal Ghosh, Dr. D.K. Pal, Dr. S.C. Datta, Dr. P. Chandran, Dr. Sanjay Ray, Dr. Nayan Ahmed and Dr. S.K. Mahapatra

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Arsenic contamination of groundwater in parts of West Bengal (India): Build-up in soil-crop systems and mitigation

Saroj Kumar Sanyal

Former Vice-Chancellor, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India
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1. Introduction

Arsenic (As), a toxic trace element, is of great environmental concern due to its presence in soil, water, plant, animal and human continuum. Its high toxicity and increased appearance in the biosphere has triggered public and political concern. Out of the 20 countries (covering Argentina, Chile, Finland, Hungary, Mexico, Nepal, Taiwan, Bangladesh, India and others) in different parts of the world, where groundwater arsenic contamination and human suffering therefrom have been reported so far, the magnitude is considered to be the highest in Bangladesh, followed by West Bengal, India (Sanyal *et al.*, 2015). The scale of the problem is grave and unprecedented, exposing millions of people in the Bengal delta basin and beyond to risk. The widespread arsenic contamination in groundwater in different parts of West Bengal, located primarily in five districts adjoining the river Bhagirathi, as well as the contiguous districts in Bangladesh, is of great concern. Even beyond the Bengal delta basin, the widespread arsenic contamination in groundwater above the permissible limit (50 µg As.L^{-1}; WHO, 2001) has also been detected in several places in the country (Table 1), for instance at Chandigarh (1976), Bihar (2002), Uttar Pradesh (2003), Jharkhand (2003-2004) (Sanyal *et al.*, 2015), Chhattisgarh and Punjab (2006-2007).

Guideline Value of Maximum Arsenic Concentration

The World Health Organization (WHO)-recommended provisional guideline value of *total* arsenic (As) concentration in drinking water is 10 µg As. L^{-1} since 1993 (WHO, 1993), mainly because lower levels preferred for protection of human health are not reliably measurable on a large scale. However, the National Standard for maximum acceptable concentration (MAC) of arsenic in drinking water is 50 µg As. L^{-1} in several countries including India and Bangladesh, based on an earlier WHO (1971) advice. The proposed new standard value of 5 µg As. L^{-1} is under consideration (WHO, 2001). This is due mainly to the fact that inorganic arsenic compounds are classified in Group 1 (carcinogenic to humans) on the basis of adequate evidence for carcinogenicity in humans and limited evidence for carcinogenicity in animals.

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Table 1. Groundwater arsenic contamination in the Indian Subcontinent

State	Coverage	Level of contamination in groundwater (μg As. L^{-1})
West Bengal	12 Districts (Malda, Murshidabad, Nadia, North 24- Parganas, South 24-Parganas, Kolkata, Howrah, Hooghly, Bardhhaman, North Dinajpur, South Dinajpur, Coochbehar),111 blocks	50-3700
Assam	18 Districts 5 Districts (Barpeta, Dhemaji, Dhubari, Darrang and Golaghat) 4 Districts (Jorhat, Lakhimpur, Nalbari and Nagaon), 72 blocks	>50 100-200 228-657
Bihar	12 Districts (Bhagalpur, Khagaria, Munger, Begusarai, Lakhisarai, Samastipur, Patna, Baishali, Saran, Bhojpur, Buxar and Katihar), 32 blocks	>50
Jharkhand	1 District (Sahibgunj)	>50
Uttar Pradesh	21 Districts (Ballia,Lakhimpur,Kheri, Baharaich, Chandauli, Gazipur, Gorakhpur, Basti, Siddharthnagar, Balarampur, SantKabir Nagar, Unnao, Bareilly, Moradabad, Rae Bareli, Mirzapur, Bijnore, Meerut, SantRavidas Nagar, Shahjahanpur and Gonda)	>50
MadhyaPradesh	1 District (Rajnandgaon)	52-88
Manipur	1 District (Thoubal)	798-986
Tripura	3 Districts (North Tripura, Dhalai and West Tripura)	65-444
Nagaland	2 Districts (Mokokchung and Mon)	>50

Source: Sanyal *et al*. (2015)

Adequate data on the carcinogenicity of organic arsenic have not been generated. The joint FAO/WHO Expert Committee on Food Additives (JECFA) set a provisional maximum tolerable daily intake (PMTDI) of inorganic arsenic by humans as 2.1 μg As. kg body weight^{-1}.day^{-1} in 1983 and confirmed a provisional tolerable weekly intake (PTWI) as 15 μg As. kg body weight^{-1}.day^{-1} in 1988 (FAO/WHO, 1989). Such guideline values for soil, plant and animal systems are not available.

2. Geogenic Origin of Arsenic Contamination in Groundwater

Two major hypotheses, both of geogenic origin, have been proposed to account for such widespread arsenic contamination in the groundwater in parts of West Bengal and Bangladesh, confined within the delta bound by the rivers Bhagirathi and Ganga-Padma. Of these two hypotheses, namely the arsenopyrite oxidation hypothesis and the ferric oxyhydroxide reduction hypothesis, the latter is more consistent with the experimental observations reported for the aquifer

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sediments and the groundwater of the Bengal delta basin (Sanyal *et al.*, 2015; Das *et al.*, 2014). According to this hypothesis, an anoxic condition of the aquifer causes arsenic mobilization from the arsenic-bearing sediments into the groundwater aquifer. The maintenance of such anoxic condition is proposed to be facilitated by the widespread practice of wetland paddy cultivation in the affected belt. Some details are given below (Bose and Sharma, 2002).

Dissolution of arsenic-rich iron oxyhydroxides (FeOOH) due to onset of reducing conditions in the subsurface

Under oxidizing conditions, and in the presence of Fe, inorganic species of arsenic are predominantly retained in the solid phase through interaction with FeOOH coatings on soil particles. The onset of reducing conditions in such environments can lead to the dissolution of FeOOH coatings. Fermentation, of peat in the subsurface releases organic molecules (*e.g.*, acetate) to drive the reducing dissolution of FeOOH, resulting in release of Fe^{2+}, As^{+3}, and As^{+5} ions present on such coatings.

The chemical reaction is given by:

$$8FeOOH - As_{(s)} + CH_3COOH + 14\ H_2CO_3 = 8\ Fe^{2+} + As_{(d)} + 16\ HCO_3 + 12H_2O$$

Where $As_{(s)}$ is sorbed arsenic, and $As_{(d)}$ is dissolved arsenic.

3. Natural Abundance

Dissolved arsenic concentrations in natural waters (except groundwater) are generally low, except in areas characterized by geothermal water and/or mining activities. The sedimentary rocks generally have higher arsenic content than do igneous and metamorphic rocks, while suspended and bottom sediments in most aquatic systems contain more arsenic than most natural waters do. The capacity to retain arsenic is primarily governed by the sediment grain-size and the presence of surface coating composed of clays, clay-sized iron and manganese oxides and organic matter. Arsenic held by solid phases within the sediments, especially iron oxides, organic matter and sulphides may constitute the primary arsenic sources in groundwater under conditions conducive to arsenic release from these solid phases. These include abiotic reactions (oxidation/ reduction, ion exchange, chemical transformations) and biotic reactions (microbial methylation) (Sanyal *et al.*, 2015).

4. Health Implications of Arsenic Contamination

Early symptoms of arsenic poisoning include skin disorders, weakness, languor, anorexia, nausea and vomiting with diarrhoea or constipation. Long-term exposure symptoms are acute diarrhoea, edema (especially of the eyelids and ankles), skin pigmentation, arsenical melanosis

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and hyperkeratosis, enlargement of liver, respiratory diseases and skin cancer. Severe cases include gangrene in the limbs and malignant neoplasm. Increased incidence of lung disease and hypertension was found in arsenic exposed people compared to unexposed ones.
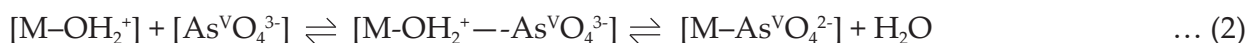
5. Chemistry of Arsenic in Groundwater-Soil Environment

Arsenic (As) in groundwater and soil is present as dissolved oxyanions, namely arsenites ($As^{III}O_3^{3-}$; $H_nAs^{III}O_3^{(3-n)-}$, with n=1, 2) or arsenate ($AsVO_4^{3-}$, $H_nAs^VO_4^{(3-n)-}$, with n=1, 2), or both, besides the organic forms. The solubility, mobility, bioavailability and hence toxicity of arsenic in soil-crop system primarily depends on its chemical form, mainly the oxidation state of arsenic.

Thus, the toxicity of arsenic compounds in groundwater/soil environment depends largely on its oxidation state, and hence on the redox status and pH, as well as whether arsenic is present in organic combinations. The toxicity of arsenic compounds in groundwater/soil environment follows the order:

Arsine [AsH_3; valence state of arsenic (As): 3]> organo-arsine compounds > arsenites (As^{3+} form) and oxides (As^{3+} form) > arsenates (As^{5+} form) > arsonium metals (+1)> native arsenic metal (0).

The arsenites are much more soluble, mobile, and toxic than arsenates in aquatic and soil environments. The organic forms, namely dimethyl arsinic acid (DMA) or cacodylic acid, which on reduction (e.g. in anoxic soil conditions) forms di- and trimethyl arsines, are also present in soil. Another organic form present in groundwater and soil is monomethyl arsonic acid (MMA). At pH 6-8, and in an aerobic oxidized environment (redox potential, E_h= 0.2-0.5V), arsenic acid species and arsenate oxyanions, that is, $H_n As^VO_4^{(3-n)-}$ ions, with n = 1, 2), (pentavalent arsenic forms) occur in considerable proportions in most aquatic systems, whereas under mildly reducing conditions (such as one encounters in flooded paddy soils with E_h = 0-0.1V), the arsonous acid, $H_3As^{III}O_3$, and arsenite oxyanion species($As^{III}O_3^{3-}$; $H_nAs^{III}O_3^{(3-n)-}$, with n = 1, 2) (arsenic in trivalent form) are the predominant species. Furthermore, As (III) is more prevalent in soils of neutral pH range (and in most groundwater), as in the soils of the affected belt of West Bengal, India and Bangladesh, than otherwise thought, and hence is of concern. This is primarily because As (III) exists largely as a neutral, uncharged molecule, namely arsonous acid, $H_3As^{III}O_3^0$ (pKa= 9.2), at the pH of the neutral soils and most natural groundwater, as one would expect from the Henderson's equation, and is thus less amenable to retention by the charged mineral surfaces in soils and sediments.

There have been both direct and indirect evidence to suggest that arsenic (and selenium) is held in soils and sediments by oxides (e.g. of Fe, Al, Mn) through the formation of inner-sphere complexes *via* ligand-exchange mechanism. This is illustrated below by the following scheme of reactions.

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$$[M–OH] + H_2O \rightleftharpoons [M–OH_2^+] + OH^- \qquad \dots (1)$$

$$[M–OH_2^+] + [As^VO_4^{3-}] \rightleftharpoons [M\text{-}OH_2^+ \text{—-} As^VO_4^{3-}] \rightleftharpoons [M–As^VO_4^{2-}] + H_2O \qquad \dots (2)$$

However, the non-specific adsorption (through electrostatic mechanism) of arsenic also occurs at pH values below the point of zero charge (PZC) for a given adsorbent (Sanyal *et al.*, 2015). As shown above, the said ligand exchange tends to increase the negative charge of the soil colloidal fraction, for instance, of iron oxides, and thus push the PZC of the arsenic-laden soil to lower pH. Indeed, this was shown to be the case with the concomitant increase in the negative magnitude of the variable-surface charge and the surface potential of the corresponding soil colloidal fraction (Sanyal *et al.*, 2015). However, the non-specific adsorption (through electrostatic mechanism) of arsenic also occurs at pH values below the point of zero charge (PZC).

It ought to be emphasized that groundwater or soil solution, which is subjected to affluxes and influxes, as well as circulation and also to man-made perturbations of groundwater due to its withdrawal, cannot be expected to remain in *thermodynamic equilibrium*, it being very much of an open system (thermodynamically speaking). Thus, *more often than not*, the ratio of concentrations of arsenic species, namely the ratio, $[(As^{III})/(As^V)]$, in field soils does *not* quite agree with the ones computed from the observed redox potential (E_h) and the application of the Nernst's equation (at 25°C) to the equilibrium redox reaction, namely

$$As^VO_4^{3-} + 2H^+ + 2e = As^{III}O^{3-} + H_2O \qquad \dots(3)$$

$$E_h \cong E^0_h - 0.0295 \log [(As^{III}O_3^{3-})]/ (As^VO_4^{3-})] + 0.059 \text{ pH} \qquad \dots(4)$$

Where the ( ) terms refer to the equilibrium concentrations of the respective ionic species in dilute soil solution, and E^0_h is the standard redox (reduction) potential of the $(As^VO_4^{3-} /As^{III}O_3^{3-})$ redox couple at 25°C. It is evident from Eq. 4 that the proportion of As^{III}, and hence soluble arsenic level in soil, should increase substantially with diminishing E_h and increasing pH. Furthermore, at a high pH, the OH^- ion concentration would increase, causing displacement of As^{III} and As^V species from their binding sites through competitive ligand exchange reactions (in presence of phosphate, sulphate, molybdate and so on in soil solution). The dependence of arsenic sorption on pH of the sorption medium is governed largely by the nature of the soil colloidal fraction.

Complexation Study

In order to assess the efficacy of organic manures as well as soil inherent organic matter, FA and HA fractions, extracted from compost, mustard oil cake, poultry manure, neem oilcake and organic manure- amended surface soils were collected from the selected contaminated sites of West Bengal. These HA/FA samples were next characterized by pH–potentiometric titrations,

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viscometric measurements, visible spectophotometry, and surface tension determinations (Mukhopadhyay and Sanyal, 2004).

The stability constant of organo-arsenic complexes was obtained from the following equations (Schnitzer and Skinner, 1966) (which were later used by Mukhopadhyay and Sanyal, 2004):

$$\log [(\lambda_0/ \lambda) - 1] = \log K + x \log [HA] \qquad \dots(5)$$

Where λ_0 and λ = Distribution constant of arsenic between the anion- exchange resin (mimicking the plant root) and the aqueous phase in the absence and presence of HA/FA, respectively.

K = stability constant of arsenate-HA/FA complex

x = number of moles of HA/FA combining with one mole of arsenate [HA] = concentration of HA/FA (mol L-1). Furthermore, λ_0 is given by

$$\lambda_0 = \alpha_0 V/ (100 - \alpha_0) g \qquad \dots(6)$$

Where α_0 = Per cent arsenic bound to the exchange resin, V =Volume of the solution and g = Mass of the resin.

The log K values for the present arsenic-HA/FA complexes fell in the order:

FA4 > FA5 > FA6 > FA2 > FA1> FA3 > HA1> HA2 > HA5 > HA6 > HA4 > HA3*.

*HA/FA: HA₁/FA₁, extracted from Nonaghata Uttarpara Soil (S₁); HA₂/FA₂, extracted from Nonaghata Dakshinpara Soil (S₃); HA₃/FA₃, extracted from Kalyani Soil (K); HA₄/FA₄ , extracted from compost (Com); HA₅/FA₅, extracted from oil cake (OC); HA₆/FA₆, extracted from the soil (S₁) treated with compost (Com) under field condition. Lower K of HA extracted from compost (HA₄) may be due to its higher hydrophobic (coiled) content of moieties (characterised by higher molecular weight and hence characterised by a higher degree of hydrophobic character), thereby rendering less reactivity with aqueous arsenate.

The release of once-complexed arsenic by the aforesaid HA and FA fractions by the competing oxyanions in agricultural system, such as sulphate, phosphate, nitrate, etc., were studied. Table 2 gives such results for sulphate and nitrate.

It is seen (Table 2) that per cent release of arsenic from the HA/FA-arsenic complexes is rather small (3-4%), and that the said release is more from the FA-arsenic complexes than those from the corresponding HA-arsenic complexes. This is no wonder since the release reaction with aqueous sulphate and nitrate takes place in aqueous phase, where more hydrophilic FA fractions are more reactive.

Surface Tension Measurement

The hydrophobic moieties such as the long alkyl side-chains of fatty acid residue impart to humic molecules an amphiphilic character, and consequently surface-active properties (Sanyal,

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Table 2. Release isotherm Paramemeters of Humic Acid (HA)/Fulvic Acid (FA)-Arsenic Complexes by Sulphate and Nitrate Ions

	Average Desorption (per cent)	
HA/FA	Sulphate	Nitrate
HA_1	3.19	3.14
HA_2	3.35	3.49
HA_3	4.04	3.93
HA_4	2.25	2.23
HA_5	3.07	3.05
HA_6	3.07	3.05
FA_1	4.16	3.94
FA_2	4.32	4.21
FA_3	4.20	4.09
FA_4	3.88	3.85
FA_5	3.93	3.93
FA_6	4.12	4.00
S.E. ($\pm$)	0.136	0.097
CD at 5%	0.370	0.201

Source: Ghosh *et al.* (2012), Sanyal (2021)

2017). Thus, humic molecules have been shown to accumulate in the interfacial layers, causing a fall of surface tension of their aqueous solutions (Chen and Schnitzer, 1978; Tombacz, 1999; Saha and Sanyal, 1888, Datta *et al.*, 2001; all cited in Sanyal, 2017) as well as their interfacial tension at water-oil interfaces.

The hydrophobic interactions in aqueous systems of macromolecules of mixed organic nature was discussed by Sanyal (1984) from rigorous thermodynamic considerations in terms of the free energy change accompanying humic accumulation in soil solution. The falling surface tension of the HAs and FAs with concentration leads to a positive surface excess (τ) of the humic molecules as is evident from the Gibbs adsorption equation, given below:

$$\tau = - (1/RT). (d\gamma/d \ln C) \qquad \qquad \dots(7)$$

Where γ is the surface tension of humic solution at absolute temperature T, and R is the Universal gas constant. The τ value was noted to increase with the increasing hydrophobicity of the HA molecules (Sanyal, 1984; Datta *et al.*, 2001) as one would expect, for the higher the hydrophobicity, the greater will be the tendency of the humic molecule to minimize its contact surface area with water, under "thermodynamic compulsion" (Sanyal, 1984). This ensures accommodation of a relatively large number of molecules per unit surface area of water. A sharp rise in τ was observed

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for humic samples in presence of neutral salts (*e.g.*, 0.1 M NaCl) which obviously results from a higher degree of "exclusion" from the aqueous system of the predominantly hydrophobic HA in presence of strongly hydrated electrolytes. In general,

$$\tau HA \gg \tau FA \qquad \ldots(8)$$

The surface pressure, π, which is defined as the lowering of surface tension of a liquid (such as soil solution) due to the formation of a monolayer of a largely hydrophobic substance (such as humic molecules) on the surface, is given by,

$$\pi = \gamma_o - \gamma \qquad \ldots(9)$$

Where γ_o and γ are the respective surface tension of the clean interface (*e.g.*, soil water/air interface) and the interface plus monolayer (*e.g.*, aqua humic acid system of soil). The variation of surface pressure with the area available to spread the material is represented by a π-A (force-area) curve. Such π-A curves may be regarded as two-dimensional equivalent of P-V curves for a three-dimensional system. The p-A curves of HAs were interpreted as indicating monolayer formation (by HA molecules) at the air-water interface. The humic complexes exhibit higher π than do the corresponding fulvic complexes (Sanyal, 2017).

The degree of aromatic character in humic acid component of soil organic matter was shown from ^{13}C NMR studies to be higher than that in the corresponding (more hydrophilic) fulvic acid fraction (Schnitzer, 2000). This is shown below in Table 3.

Thus **Aromaticity$_{HA}$ > Aromaticity$_{FA}$**

This is in agreement with the findings from the surface tension measurements.

Table 3. Distribution of C (%) in a Haploboroll HA and a Spodosol FA as determined by ^{13}C NMR spectroscopy

Chemical shift range (ppm)	Per cent of carbon (C)	
	HA	FA
0-40	24.0	15.6
41-60	12.5	12.8
61-105	13.5	19.3
106-150	35.0	30.3
151-170	4.5	3.7
171-190	10.5	18.3
Aliphatic C (0-105ppm)	50.0	47.7
Aromatic C (106-150 ppm)	35.0	30.3
Phenolic C (l51-170 ppm)	4.5	3.7
Aromaticitya	44.1	41.6

a[(Aromatic C + phenolic C)/(Aromatic C + Phenolic C +Aliphatic C)] x 100
Source: Schnitzer (2000); Sanyal (2021)

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6. Arsenic in Soil-Plant System

Several workers have reported accumulation and transformation of arsenic by a number of plant species grown in the arsenic affected areas. These crops (such as rice, elephant-foot-yam, green gram, cowpea, sesame, groundnut, etc.) tended to show a build-up of arsenic in substantial quantities in different plant parts. Indeed, pointed gourd, a vegetable creeper plant, has shown considerable arsenic loading when cultivated in the contaminated soils of West Bengal. A number of other vegetables, namely cauliflower, tomato, bitter gourd were also noted to accumulate arsenic in their economic produce. The distribution of arsenic content in plant parts generally followed the order:

Root > stem>leaf > economic produce.

As mentioned earlier, reduction of arsenate to more toxic arsenite is facilitated by lowering of the redox potential (E_h) which is encountered under anoxic soil conditions, with arsenite being more soluble and mobile than arsenate. Rice plant is thus rather susceptible to arsenic toxicity since it is grown under submerged soil conditions (low E_h). Further, the processing of rice (i.e., parboiling and milling, etc.) was found to increase the arsenic loading in rice for both the traditional and the high yielding cultivars (Sanyal et al., 2015). The toxicity of arsenic species in plant body is reported to follow the order:

Arsine (AsH_3) > As^{3+} >As^{5+} > MMA (Monomethyl arsonic acid) > DMMA (Dimethyl arsinic acid) (cited in Sanyal, 2017)

On storing the arsenic contaminated groundwater (from a shallow tube well, STW) in a pond, there was a gradual lowering (on standing) of arsenic loading of the stored pond water, while its progressive build-up in the corresponding pond sediment samples. Such decrease of arsenic content in the stored water might have arisen from the sedimentation of arsenic from the water to the pond sediment which obviously increases the arsenic loading in the latter. The dilution of the stored water by rainfall during the wet season (July to September) further decreased the contamination in the water. This opens up the possibility of conjunctive use in agriculture of surface and groundwater during the *lean period* (January to May of no or little rainfall) as a potential remedial option (Sanyal et al., 2015).

7. Arsenic in Soil-Plant System and its Influence on Food-Chain

It was noted that As (III) accounted for the major arsenic species recovered from grains of the transplanted autumn paddy, while As (V) predominates in that from rice straw (Sanyal et al., 2015). Soil amendment through organic intervention reduced arsenic accumulation in rice grain and straw of autumn rice as manifested through the reduction of inorganic arsenic (Sinha and Bhattacharyya, 2014a). Sinha and Bhattacharyya (2014b) also studied the arsenic toxicity profile

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in rice, grown in contaminated area of rural West Bengal, and the possible risk of its dietary exposure. The unique character of the anaerobic rice ecosystem results in a significant build-up of inorganic arsenic (i- As) in soil and its concomitant accumulation in rice. The recoveries of i-As was dominated by As (III) in rice grain and As (V) in rice straw, thereby emphasizing the presence of higher levels of the more toxic As (III) in the edible portion. Recoveries of organic arsenic species in rice grain and straw further suggested the possibilities of methylation of i-As in the plant system (Figure 1). The risk of dietary exposure to i-As through rice, the staple food in the rural Bengal, poses an almost equal threat to human health as that posed by the contaminated drinking water. Organic amendments and augmented P fertilization showed considerable promise in reducing total and inorganic arsenic accumulation in rice and the consequent dietary risk (Sinha and Bhattacharya, 2014b, Sanyal *et al.*, 2015).
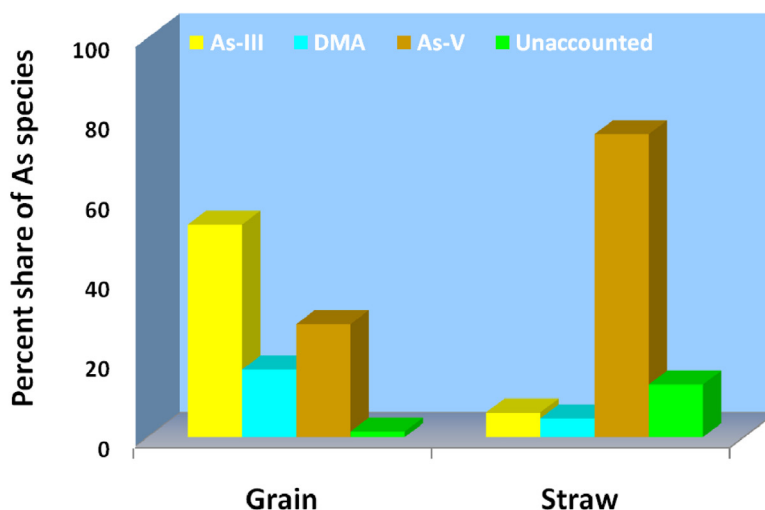

Figure 1. Per cent share of arsenic species in grain and straw of *Boro* rice
Note: Toxicity of Arsenic: As (III) >> As (V) > Organic forms (Monomethyl arsonic acid and dimethyl arsenic acid)
Source: NAIP (2012), Sanyal (2021)

Few reports are available that characterize daily arsenic (As) exposure through water and diet among the people living in groundwater contaminated regions and correlate the former with arsenic biomarkers. Demographic characteristics and the total daily As intake through water and diet were determined in 167 participants (Group-1 participants, selected from As-endemic region) and 69 participants (Group-2 participants, selected from As-non-endemic region) in a study conducted in West Bengal. The findings showed significantly high dietary arsenic intake in people living in Nadia district of West Bengal, where contaminated groundwater was used for irrigation purpose, but significantly low in the region of Hooghly district, where groundwater was

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uncontaminated. Even after lowering the As level in drinking water to < 50 µg As. L^{-1} (the permissible limit in India), significant As exposure occurred through water and diet, reflected by the elevated level of As in the arsenic biomarker, namely urine, in the people living in the As-endemic region studied. Those with skin lesions were found to have a higher level of arsenic in urine and hair, compared to those without skin lesion (Guha Mazumder *et al.*, 2013, 2014). In yet another study, the dose of daily As intake from both water and diet was found to be significantly and positively associated with urinary As levels in an As-endemic region of West Bengal, even when people were using As-safe water (< 50 µg As. L^{-1}) for drinking and cooking purposes (Figure 2). When arsenic levels in drinking water were further reduced to < 10 µg As. L^{-1} (WHO safe limit), the dose from the diet was still found to be significantly associated with urinary arsenic excretion (Figure 3). But no significant association was found with arsenic dose from drinking water in this group (Halder *et al.*, 2012; Guha Mazumder *et al.*, 2013; Sanyal *et al.*, 2015). Further, when exposed to arsenic through only diet, urinary arsenic concentration was found to correlate positively with dietary arsenic intake in the participants, showing skin lesions, while this correlation was insignificant in participants without skin lesion. Thus Figures 2 and 3, taken together, amply demonstrate that supply of arsenic-safe drinking water (< 10 µg As. L^{-1}) to the population in rural Bengal *alone is not enough to reduce the risk of arsenic poisoning*, consumption of *rice provides yet*
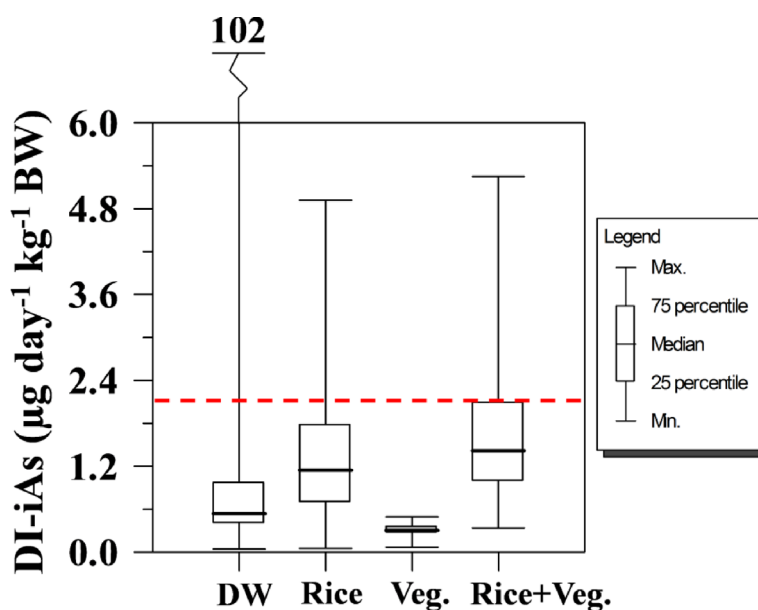

Figure 2. Comparison among daily intake of inorganic As (DI-iAs) due to consumption of drinking water (DW), rice and vegetables (Veg.)
The (red) dotted line indicates WHO recommended provisional maximum tolerable daily intake (PMTDI) (PMTDI$_{As}$) value of 2.1 µg As. kg body weight^{-1}. day^{-1}
Source: Halder *et al*. (2012)

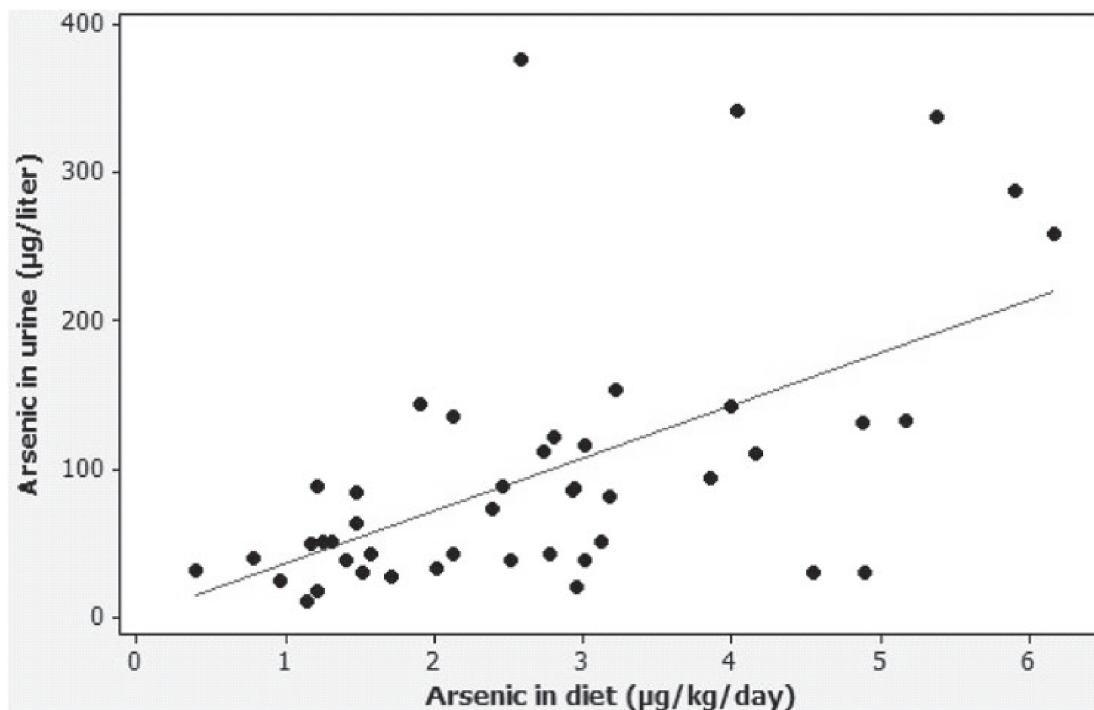*23rd Annual Convention of The Clay Minerals Society of India and National Conference on*
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Figure 3. Correlation of urinary arsenic concentration (µg As. L^{-1}) with daily dietary arsenic intake (µg As. kg^{-1} day^{-1}) for participants, drinking water with arsenic level < 0.3 µg As. L^{-1}, having skin lesion (n = 45), West Bengal, India (r = 0.573)
Source: Guha Mazumdar *et al*. (2014)

another potential pathway of inorganic arsenic (i-As) exposure, that must also be considered for the effective remedial options. Indeed, any mitigation intervention of chronic arsenic toxicity in rural Bengal needed integrated approaches of attempting to reduce arsenic entry into the food-chain, on one hand, while reduction of arsenic in the drinking water below the safe limits, on the other (Halder *et al*., 2012; Guha Mazumder *et al*., 2014; Sanyal *et al*., 2015).

8. Risk Assessment of Metal/Metalloid-Contaminated Soil

Risk assessment of metal/metalloid (e.g., arsenic)-contaminated soil depends on how precisely one can predict the solubility of metals in soils. Such risk of metal contaminated soils can also be assessed by predicting the metal uptake by crops grown on contaminated soils on routine basis. To ascertain this, simpler approaches like integrated solubility and free ion activity model (FIAM) (Jopony and Young, 1994; Datta and Young, 2005) have been successfully used to predict arsenic uptake by rice and wheat grown on selected contaminated soils in Malda district of West Bengal. By a series of transformations applied to FIAM, one obtains the final form of FIAM showing the

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arsenic loading of these crops as a function of the selected soil properties, namely soil pH and soil organic matter (see later).

9. Hazard Quotient (HQ$_{gv}$)

Risk to human health (**Hazard Quotient, HQ$_{gv}$**) for intake of metal through consumption of green leafy vegetables is computed as:

HQ$_{gv}$ = (ADD/R$_f$D), HQ $_{gv}$ > 1.0 suggests hazard to human health.

Where ADD = average total daily dose of metal intake (mg metal/kg body weight/day) through diet and drinking water; R$_f$D= reference dose and Permissible limit of mg metal uptake/kg bw / day. For arsenic, as mentioned earlier, it is 2 µg arsenic/kg body weight /day.

For any given food item, HQ $_{gv}$ > 0.5 is taken to suggest hazard (Meena *et al.*, 2016) (Table 5).

10. Solubility and Free Ion Activity Model (FIAM)

Prediction on of arsenic uptake by rice grown in affected soils of Malda district of West Bengal under arsenic-contaminated groundwater irrigation is made as follows (FIAM):

$$p(M^{2+}) = [p(M_c) + k_1 + k_2 \, pH)]/ \, n_F \qquad \qquad …(10)$$

$$\text{Transfer factor} = \log [M_{plant}/(M^{2+})] \qquad \qquad …(11)$$

Equations 10 and 11 can be combined to lead to Equation 12:

$$p(M_{plant}) = C + \beta_1 \, pH + \beta_2 \, p(M_c) \qquad \qquad …(12)$$

Where

(M^{2+}): free metal ion activity in soil solution (Eq. 10)

M$_c$: EDTA-extractable metal assumed to be exclusively adsorbed on humus (Eq. 12)

k$_1$ and k$_2$: Empirical constants expressing pH-dependence of metal distribution coefficient (Eq. 10)

M$_{plant}$: Metal loading in plant biomass (Eq. 12)

C, β$_1$ and β$_2$: Empirical metal- and crop-specific constants (Eq. 12).

Table 4 and the associated Figure shows a highly significant correlation between the measured arsenic uptake by rice crop and the predicted uptake as obtained by fitting the experimental data to FIAM.

The point to be noted (Table 5) here is that the mean value of HQ for arsenic was much higher than 1.0 in case of drinking water, whereas the same for all the three cereals were also less

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Table 4. Prediction of arsenic uptake by rice grain as a function of soil pH, Walkley-Black organic carbon and extractable metals/metalloid

Metalloid	Rice grain			
	Parameters			R^2
	C	β_1	β_2	
Arsenic	-2.0659	-0.0619	0.7766	0.77

The values of $R^2 > 0.20$ are significant at 5% probability level
*Highly significant
Source: Golui *et al.* (2017)
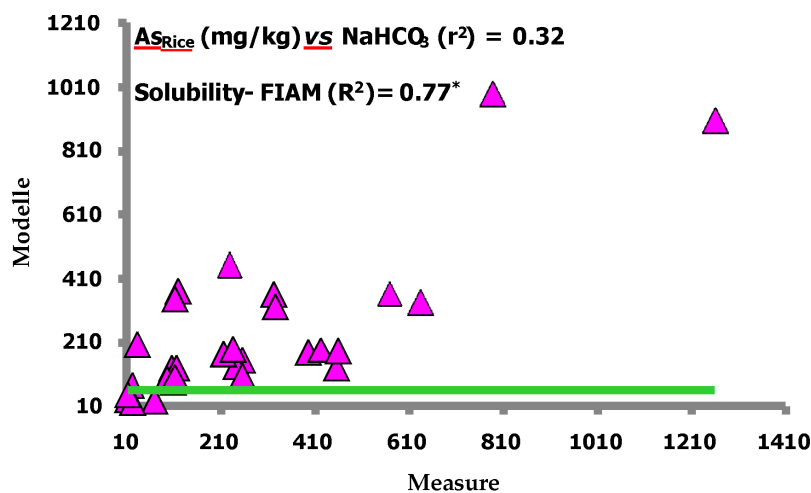
Table 5. Hazard Quotient (HQ) for human intake of arsenic through consumption of crops grown on farmers' field

Source of Arsenic	HQ for Arsenic		
	Mean	Range	S.D. (±)
Drinking water	3.89	0.167-12.0	3.371
Rice	0.375	0.014-1.71	0.368
Wheat	0.114	0.007-0.451	0.141
Maize	0.112	0.031-0.347	0.099

Source: Golui *et al.* (2017)

than 0.5. However, the range of values of HQ for rice suggests that in many farm fields, the HQ will be more than, not only 0.5, but also more than 1.0. This indicates that the rice- based diet provides *yet another potential pathway for the toxic arsenic intake, thereby adversely impacting the human health.*
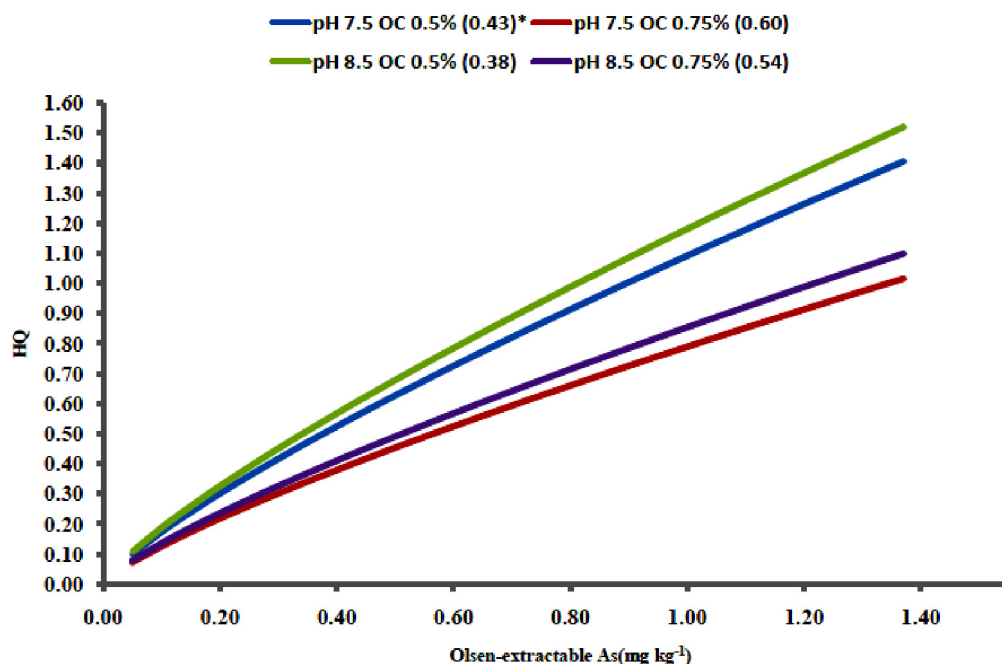
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Figure 4. Permissible limit of Olsen-extractable As in soils in relation to soil pH
Source: Golui *et al.* (2017)

Thus it is noted that with the increase of pH and/or organic matter content in soil, the Olsen-extractable arsenic (labile pool of arsenic) shifts towards higher values corresponding to the value of HQ = O.5. Thus, the permissible limit of Olsen-extractable arsenic in the soil of the farmers' fields was noted to be 0.43 mg kg^{-1} for rice cultivation, if the soil pH and organic carbon content were 7.5 and 0.50%, respectively, while these values would be 0.54 mg kg^{-1}, if soil pH and organic carbon were 8.5 and 0.75%, respectively (Figure 4). This is in agreement with the aforesaid description of arsenic retention by the humic and fulvic acid fractions of, not only the indigenous soil organic matter, but also those of the incorporated organic manures.

11. Arsenic Remedial /Mitigation Options

- Optimum conjunctive use of ground and surface water (e.g. using harvested rainwater during lean period of rainfall) and recharge groundwater resource.
- Irrigation with pond-stored groundwater – decontamination is facilitated by rainfall and sedimentation.
- Enhance water use efficiency (optimum water management).
- Prefer low-water requiring farmer-attractive cropping sequences (especially for the lean period of no or low rainfall).

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- Increased use of FYM and other manures + green manure crops, inclusion of pulses/other legumes in the cropping sequence, as well as application of appropriate inorganic amendments (Zinc /Iron /Silicon salts as and where applicable).

- Identification/development of varieties /crops which accumulate less arsenic in the consumable parts and where the ratio of inorganic to organic forms of arsenic is low.

- Development of cost-effective phyto-(choice of especially rhizo- exclusive crops) and bio-remediation techniques.

- Creation of general awareness through mass campaigning, holding of farmers' day, field demonstrations, with due care being given to the socioeconomic factors.

Source: Sanyal (2021)

12. Policy Interventions

Arsenic contamination in groundwater in parts of the country and its adverse effect on human health have been agitating the scientists, physicians, community workers, lawmakers and the general public at large, especially those who are suffering from its toxic effect.

The primary attention so far, however, is directed towards solving the problem of such contaminated resource-based drinking water supplies to mostly the rural population.

The food-chain issue received less attention, *notwithstanding* the fact that quite a vast amount of experimental data have been already generated by not only the agricultural scientists, but also the geologists, hydrogeologists, environmental experts and, most of all, the medical professionals (the latter till date in a moderate scale though) working in a consortium mode.

Thus, it is quite reasonably well-established now that the food-chain contamination provides *yet another potential pathway of arsenic exposure* of the population in rural areas.

It is thus imperative that any comprehensive mitigating intervention of chronic arsenic toxicity in people requires integrated approaches towards decreasing the arsenic entry into the food-chain, while reducing arsenic in the drinking water below the safe limits at the same time. Without this, the food bio-safety concern is unlikely to go hand-in-hand with the food and nutritional security concerns of the country, not only for the domestic population but also for the export market.

It appears that despite such realization at the level of scientists, it is yet to translate itself in terms of a concrete action plan, perhaps as a pilot programme initially, and ûnally as a large-scale initiative, to be implemented covering the entire affected belt. *To ensure the latter, the concerned planners and the policymakers need to be adequately sensitized* (Sanyal, 2021).

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A study on the use of proximally sensed soil data as a proxy to soil analysis and its mapping

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Three hundred geo-referenced surface soil samples and twenty four soil profiles of from Varanasi region (comprising of the districts of Varanasi, Chandauli, Sant Ravidas Nagar and Mirzapur) and were used in the present investigation. Eight soil physical and chemical properties such as pH, electrical conductivity (EC), organic carbon (OC), available phosphorous (P), available potassium (K), sand, silt and clay were analyzed for developing prediction models using spectral data in the near infrared (NIR) and mid infrared (MIR) range, collected under laboratory conditions. Reflectance (R) and absorbance (A) and their first and second derivatives were evaluated for developing prediction models and it was found that models developed using raw spectral data yielded better predictions. Spectral correlation analysis revealed that in comparison to physical parameters, chemical composition had poor correlations. The soil chemical and physical properties namely available P, available K, sand and silt showed higher correlations in specific wave bands such as 1880-1890,1960-2460 nm; 1130 to 1170 nm; 2180-2190, 2384-2500, 3290-3390,4180-4190 nm and 350-400 nm, 2694-2698 respectively. Based on ratio of performance deviation (RPD) of the calibration models of NIR, Partial Least Square Regression (PLSR) was found suitable for pH, EC, available K, sand, silt and clay content whereas Multivariate Adaptive Regression Splines (MARS) model for organic carbon and available phosphorus. In the MIR region, PLSR was found suitable for all analysed properties except pH which was best calibrated with Support Vector Regression (SVR) model. From the validation results PLSR model of for NIR region was found better for all analysed soil properties. In the MIR region PLSR was found better for pH, organic carbon, available P, sand, silt and clay content prediction; EC was better predicted by Random Forest (RF) and available K which better predicted by SVR model. The soil data were interpolated using Stable, Exponential, Spherical and Gaussian models of ordinary krigging and it was found that ordinary krigging produced good semivariograms. Inverse distance weighted (IDW) was used to plot spatial variability maps of soil properties, and from interpolation maps it is clear that maximum area is under pH from 7.5 to 8.5, were non saline, low in organic carbon, medium in soil available P and potassium and clay loam to loam in textural. They belonged to the order Inceptisol and Alfisol and were classified upto great group level on the basis of pedon characteristics.

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Trichoderma-Azotobacter biofilm-based formulation enhances natural plant defense and antioxidant enzymes in wheat and cotton

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Microbial biofilms are gaining importance in agriculture, due to their multifaceted agronomic benefits and resilience to environmental fluctuations. However, establishment of inoculated biofilms and their effect on plant defense and antioxidant enzyme activities are less investigated. This study focuses on comparing the influence of single inoculation-*Azotobacter chroococcum* (*Az*) or *Trichoderma viride* (*Tv*) and their biofilm (*Tv–Az*), on plant defense and antioxidant enzyme activities in wheat and cotton. Application of microbials as biofilm (*Tv-Az*) proved superior in terms of enhancing constituent plant defense and antioxidant enzyme activities in shoots and roots of wheat and cotton, over control. In wheat, *Tv-Az* treatment exhibited higher peroxidase (PO) activity in roots (102%) and leaves (62%) compared to the RDF. *Tv-Az* enhanced catalase (CAT) activity by 65% and 18%, for root and shoot by. *Tv-Az* increased the phenylalanine ammonia lyase (PAL) activity by 28% and 41% in root and leaf samples. In cotton, *Tv-Az* enhanced PO activity by 65% and 45% in roots and leaves, respectively. The *Tv-Az* treatment enhanced polyphenol oxidase activity (PPO) in cotton roots (117%) and leaves (75%). The *Tv-Az* treatment recorded an increase of 54% and 32% root and leaf CAT activity and 41% and 40% of PAL activity. Enhancement in enzymatic activities was facilitated by the synergistic association between *Tv* and *Az*. Our study demonstrates the utility of *Tv–Az* biofilm as a natural inducer of plant defense and antioxidant enzyme activities in crop plants, which can sustain plant health under several biotic and abiotic stresses.

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Evaluating methods of available potassium in Vertisols in relation to their mineralogy

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Anomaly in 1 N NH_4OAc extractable K with plant uptake in some shrink-swell soils of Peninsular India was the basis of the present study which also evaluated the various methods of extraction of potassium. Five benchmark Vertisols, *viz.* Nimone series, Panjari series and PDKV, Akola series from Maharashtra, Teligi series from Karnataka and Kheri series from Madhya Pradesh were chosen for the present study. In addition, to study potassium uptake, 28 surface soil samples from different cotton experiments. The results of different forms of potassium showed that 1 N NH_4OAc extracted higher values of K than the plant available K and does not show significant correlation with plant uptake K and not the 1 N HNO_3 method. The study also suggested that non-exchangeable K by $NaBPh_4$ method provides a better alternative to express plant K uptake values for optimum fertilizer recommendation.

The fine clay smectite CEC, reduced CEC (tetrahedral CEC), and octahedral CEC were experimentally determined and the charge densities were derived from the CEC values. This showed that tetrahedral CEC and charge were higher than the corresponding octahedral values. Relationships were drawn between layer change densities and different forms of K. The higher value of tetrahedral charge in smectites is indicative of its more proneness towards isomorphous substitution and may results in adsorption/desorption of K. This information and the results of the work can be used effectively for monitoring and management of potassium fertilizers and their optimal use in shrink-swell soils.

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Nanoclay polymer composite (NCPC) based micronutrient formulations for increasing its use efficiency in rice and wheat rhizosphere

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Zn deficiency is a widespread phenomenon globally. Moreover, conventional Zn fertilizer sources when applied to soils have very low use efficiency (1-5%) owing to its interaction with soil components. An attempt was made in formulating series of novel zincated nanoclay polymer composites (ZNCPCs), starch grafted zincated nanoclay polymer biocomposites (SZNCPBCs) and chitosan grafted zincated nanoclay polymer biocomposites (CZNCPBCs) with variable percentage of commercial bentonite and nanobentonite (8%, 10 % and 12 % of monomer for each case). Polyacrylic acid-Polyacryamide copolymer was synthesized using N, N-Methylene bisacrylamide (NNMBA) as crosslinker and ammonium persulfate (APS) as initiator. Novel processes of preparing bionanocomposites viz. starch grafted (SZNCPBCs) and chitosan grafted Zincated nanoclay polymer biocomposite (CZNCPBCs) were standardized. Zn was loaded as Zn-citrate during in-situ polymerization. Clays as well as ZNCPCs, SZNCPBCs, CZNCPBCs were characterized by of X-ray diffraction (XRD), Scanning Electron microscopy (SEM), Transmission electron microscopy (TEM) and Fourier transform infrared spectroscopy (FTIR).

All nanoclay polymer composites (NCPCs) were evaluated in terms of controlled release of Zn in two Zn deficient soil (Typic Haplustepts) under laboratory incubation (15, 30, 45 and 60 days) experiment in comparison with conventional Zn sources ($ZnSO_4.7H_2O$). It was found that formulations having 12 % nanoclay showed slowest release rate. ZNCPCs were also effective in increasing Olsen-P content in soil owing to presence of citrate as carrier of Zn in ZNCPCs. However, Olsen-P content in soil was higher in NCPCs containing 8 % clay due to its faster release rate as compared with other treatment combinations. Formulation containing 8 % clays showed highest equilibrium water absorbency at a particular tension. Biodegradation study of NCPCs were carried out in laboratory incubation experiment (30, 60 and 90 days) and inoculation with fungal species (*Aspergillus* spp. and *Trichoderma* spp.) was done along with NCPCs. Results of biodegradation study revealed that *Aspergillus* spp. was much more effective as compared with Trichoderma spp. in terms of cumulative evolution of CO_2-C. Introduction of naturally occurring biopolymers (starch and chitosan) increased biodegradability of NCPCs in soils. Chitosan grafted copolymer recorded faster degradation rate as compared with starch grafted copolymer, however cumulative CO_2-C

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evolution at the end of incubation periods was higher in later as compared to former. Biocomposites (SZNCPBCs and CZNCPBCs) recorded slower release of Zn as compared to ZNCPCs as well as higher equilibrium water absorbency at a particular tension. Based on laboratory experiment ZNCPCs (having 10 % clay content) containing 6.59 % Zn was selected for pot experimentation.

ZNCPCS at two doses (5.0 mg Zn kg^{-1} and 2.5 mg Zn kg^{-1}) were tested in pot experiments alongwith conventional Zn sources (ZnSO$_4$. 7H$_2$O) (@ 5.0 mg Zn kg^{-1}) in two Zn deficient soils (Typic Haplustepts I and Typic Haplustepts II). Observations were taken at different growth stages of rice (maximum tillering stage and panicle initiation stage) and wheat (crown root initiation stage and panicle initiation stage) in rhizosphere (with plants) and non-rhizosphere (without plant) conditions. Soil Zn application through ZNCPC (@ 5.0 mg Zn kg^{-1} soil) increased DTPA extractable Zn content in rhizosphere soil irrespective of soil types to the tune of 157% (Typic Haplustepts I) to 137 % in (Typic Haplustepts II) at panicle initiation stage in comparison with conventional Zn sources (ZnSO$_4$.7H$_2$O) in rice cropping. Corresponding increase in wheat cropping was 120% (Typic Haplustepts I) to 145 % in (Typic Haplustepts II) respectively at heading initiation stage. Zn content in biomass at panicle imitation stage increased upto 73 % and 78 % in Typic Haplustepts I and Typic Haplustepts II respectively under (@ 5.0 mg Zn kg^{-1} soil (through NCPC)) treatment. Corresponding increase in Zn content in wheat biomass at heading imitation stage were 88 % and 81 % in Typic Haplustepts I and Typic Haplustepts II respectively. ZNCPCs increased Olsen-P content in soils as well as P uptake in both soil owing to solubilization of inorganic P through citrate action and organic-P through increase in acid and alkaline phosphatase activity.

ZNCPC was evaluated in filed experiments in rice crop. Nano Zn carriers (ZNCPC at three doses 100%, 75% and 50%) and nano ZnO were further evaluated in comparison with ZnSO4· 7 H2O a field experiment under rice (Rajendra Mahsuri) rhizosphere. DTPA Zn was significantly increased under 100% ZNCPC (1.78 mg kg^{-1}). Sequential Zn fractionation revealed that under ZNCPC treatments there was significant increase of water soluble, exchangeable and organically bound Zn, whereas there was significant increase of residual and specifically adsorbed Zn under ZnSO$_4$·7H$_2$O. Grain Zn content was maximum under 100% ZNCPC treatment (43.91 mg kg^{-1}) followed by nano ZnO (36.89 mg kg^{-1}). Maximum AZR (Apparent Zn recovery) was found in case of 100% ZNCPC (26.05%) followed by 75% ZNCPC (20.72%) and nano ZnO (18.23%). ZNCPC was found to be promising Zn formulation in increasing Zn use efficiency. Nano ZnO at foliar spray proved to be effective in increasing grain Zn concentration.

One study was conducted where synthesis and characterization of two novel Mn nano fertilizers i.e., nano MnO$_2$ (NMO) and Manganese nano clay polymer composites (Mn-NCPC) were attempted. Nano MnO$_2$ and Mn-NCPC contained 57.47% and 5.97% Mn. Nano Mn fertilizers i.e., Nano MnO$_2$ and Mn-NCPC (at three soil applications doses of 25%, 50% and 100%) along with nano MnO$_2$ foliar application were further investigated in comparison with MnSO$_4$.H$_2$O and control

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in a pot culture experiment under Wheat (HD-2967) crop. Application doses of Mn at 25% through nano MnO_2 or Mn-NCPC maintained statistically at par DTPA-Mn content to 100% dose of Mn through MnSO4.H2O. Sequential Mn fractionation divulged that under nano MnO_2 and Mn-NCPC treatments there were s significant increase in water soluble, exchangeable, specifically absorbed and organically bound Mn pools. Mn-NCPC 100% and nano MnO_2 100% recorded 9.85% and 11.65% more grain yield compared to control (No Mn). Mn-NCPC significantly increased acid phosphatase (APA) and alkaline phosphatase (ALPA) activity in post-harvest soils. Maximum Apparent Mn recovery (AMR) was recorded in 25% Mn-NCPC (31.71%) followed by 50% Mn-NCPC (25.59%) and 25% nano MnO_2 (24.55%).

However, NCPC based micronutrient nanoformulations need to be evaluated in long-term experiment in various soil types and cropping system for evaluating benefit: cost ratio and wide scale farmers' adaptability.

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Forms and distribution of soil acidity in surface and subsurface under different landform and land use in tropical humid region of India

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In soils of the humid tropics, acidity is a major natural threat. Heavy rainfall leads to leaching of bases, acids released during mineralization of organic matter, application of acid forming external chemical fertilizers and lack of good agriculture management practices are the major reasons for formation of soil acidity. To know the forms and distribution of soil acidity in surface and sub surface in different landform and land use a case study was taken at Elamdesam block, Idukki district, Kerala. 28 soil profiles from different land uses from upland and lowlands were analysed for water extractable acidity, KCl extractable H and Al and $BaCl_2$ acidity. Aluminium saturation was calculated using exchangeable Ca, Mg, K and Na contents in soil. Results reveals that, soils are extremely acid to strongly acid in surface (pH: 4.44 to 5.22) to extremely acid to moderately acidic in subsurface (pH: 4.16 to 5.68). KCl exchangeable H ranged from 0.17 to 2.45 meq/100 gm in surface and up to 3.19 meq/100 gm in subsoil. KCl exchangeable Al ranged from 0.22 to 0.96 meq/100 gm in surface and up to 1.73 meq/100 gm in subsoil. $BaCl_2$ acidity ranged from 1.65 to 23.27 meq/100 gm in surface and up to 26.60 meq/100 gm in subsoil. Al saturation ranged from 13.80 to 43.52% in surface and up to 70.92% in subsoil. Soils of uplands were having more exch. H, exch. Al and $BaCl_2$ acidity than lowlands. Among land uses, rubber plantation have more exchangeable (H+Al) acidity followed by oil palm, paddy and mixed plantation. Similar trend noticed for $BaCl_2$ acidity. However, Aluminium saturation is higher in rubber plantation followed by mixed plantation, oil palm and paddy land use. Recommendation of burnt lime is necessary in surface soil to ameliorate and in to subsoil gypsum too should be applied.

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Desorption of arsenic from different clay-sized fractions of soils

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Arsenic (As) is one of the most toxic elements among various heavy metals and pose to potential risk for groundwater contamination and its entry in the food chain. The release of As from soil solid phase to solution phase depends on various soil factors, such as types of clay minerals, organic C content, pH, temperature etc. Therefore, a laboratory experiment was conducted to study the desorption behavior of As from clay sized fractions of two different soil orders namely – Alfisol and Inceptisol at varying pH (5.5 and 7.0) and temperature (298 and 308 K). The clay-organic complex (COC) was separated from soil and subjected to different chemical treatment to sequentially remove the organic C (was considered as clay-oxides) and aluminium (Al) and iron (Fe) oxides (was considered as clay). The cumulative As desorption was higher in Alfisol as compare to the Inceptisol, however, the percentage of desorbed As was higher in Inceptisol as compared to Alfisol. The cumulative desorption of As from COC was higher at pH 5.5 as compared to pH 7.0. However, the percentage of desorbed As from COC was higher at higher pH and at higher temperature in both the soil orders. Irrespective of soil orders, among the clay sized fractions, the percentage of desorbed As was highest in clay. The desorption index of Alfisol was higher in comparison to Inceptisol and found to be 0.94 and 0.63, respectively. The types of clay minerals, Al-Fe-oxides, contents of organic C and pH are the major factors which determine the desorption behavior of As in soil.

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Clay mineral, pozzolanic activity

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Crude clay containing 15.9 wt.% of gibbsite were calcined at 600 °C to increase is reactivity. Both of samples were submits to physico-chemical analysis and attacked by $Ca(OH)_2$ solution according to the modified Chapelle test. The calcined product was substituted in Portland cement at 10 and 20% mass to elaborate mortars whose flexural, compressive strengths and strength activity index as well as infra-red spectroscopy, XRD, and MEB, were evaluated. The results show that calcined kaolinite has highly pozzolanic activity (1665 mg of $Ca(OH)_2$/g). 10% substitution of calcined clay on mortar give the highest swelling performance with the best mechanical properties (54.5 Mpa) than 20 % (51.3 Mpa) at 28 days. The swelling performance of the mortars have great impact on their flexural strength. The FTIR result shows that mortars with 10 % by mass replacement of calcined clay present a greater proportion of C-S-H, with greater activity index.

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Application of clays in environmental protection

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Growth of population, rapid industrialization and increasing urbanization have contributed to an increase both in the quantity and variety of solid wastes (toxic, non-toxic, flammable, radioactive, infectious etc.) generated by industrial, mining, agricultural, and domestic activities. Since the standard of living of a huge population demands increased productions in all the above four sectors, a sustainable growth model is the only solution with proper management of the wastes, which are the inextricable by-products of the growth. Considering the huge quantity of the wastes and their highly heterogeneous nature, the materials to be used for their management must be abundant, readily available, inexpensive, and at the same time versatile enough in handling different types of wastes. Clay minerals, especially those belonging to the smectite and vermiculite groups, are among the very few substances available to mankind that satisfy all these criteria. The other clay minerals also play important roles in the remedial treatment of hazardous waste. This presentation describes the application of clays in the waste management, which are essential for protection of the environment and human health and to supports sustainable economic growth, without compromising the quality of life.

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Influence of clay distribution and slope position on mango colour and yield in South-Eastern Ghat (SEG) of India

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South Eastern Ghat (SEG) ecosystems are a remarkably diverse ecosystem, mainly characterised by hillslope, foothills, upland, pediments and lowland i.e., slope variation as a function of slope angle and slope aspect. Slope angle, aspect, and elevation are considered as the primary factors for spatial variation in soil characteristics and mango fruit colour, growth and development. Differences in slope aspect cause differences in soil physical (texture, gravels and AWC), chemical (pH, EC, CEC, Exchangeable cations and nutrients) and biological properties (OC, microbial activity and root growth). Based on that a case study was attempted in Kaveripattinam block, Krishnagiri district of Tamil Nadu covering the Southern part of Eastern Ghat. Five typifying (P1 to P5) soil pedons were selected based on the mango colour and fruit was collected for analysis of quality parameters (weight, skin, pulp, seed, pH, acidity and TSS). The soils are shallow to very deep, poor to moderately well-drained, colour varied from reddish-brown to dark brown. The clay content varied from 7.54 to 34.45%. High clay content (>35%) was observed in subsoils of P2, P4 and P5. Soil reaction varied from moderately acidic to slightly alkaline (pH 5.31-8.47) and electrical conductivity (EC) was ranging from 0.03 to 0.30 dS m^{-1}. OC content was low to high (0.02–2.05%) and CEC and base saturation (BS) ranged from 4.27 to 18.41 cmol (p+) kg^{-1} and 51-100%, respectively. Fruit quality varied in weight (409 to 543 g), pulp (286 to 388 g), seed (36 to 48.5 g), pH (4.22 to 5.45), acidity (0.36 to 0.51) and TSS (13.9 to 19). Assessing the soil characteristics and fruit colour, quality and yield indicated that mango colour development was taken in loamy sandy to sandy loam texture, hillside slope with a slope ranging from 3-8%, where highest sunlight received. Whereas fruit quality was improved in P4 and P5, sandy clay loam texture, deep soil profile. Best marketable quality mango was contributed by moderately deep to deep and sandy loam to sandy clay loam texture with the upland situation. Varying microclimatic zonation and soil properties like clay distribution are closely associated with mango colour development and getting higher yields.

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Effect of pedogenic clay on soil organic carbon stability

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Mechanisms of soil organic carbon (SOC) stabilization has received much focus recently due to its relevance in controlling the global C cycle. Clay minerals are known to stabilize SOC through mechanisms such as, ligand exchange, polyvalent cation bridging, electrostatic attraction, H-bonding and van der Waals forces. Previous studies mainly focused on clay organic interaction derived from geological deposits, however, the effect of pedogenic clay on SOC stability is still lacking. Keeping that in view, soils of four different clay mineralogy were evaluated for its carbon mineralization, labile C fractions such as, SOC, microbial biomass carbon (MBC), dissolved organic C (DOC), permanganate oxidizable C ($KMnO_4$-C), Walkley Black C (WBC), particulate organic matter carbon (POM-C), complex organic matter carbon (COM-C) and their relationship with specific surface area (SSA), cation exchange capacity (CEC) and amount of clay. The results indicated that the cumulative C mineralization was highest in Mollisol and Vertisol which was dominated by kaolinite+illite mixed clay minerals and smectite/vermiculite interstratified minerals, respectively whereas alfisol showed lowest mineralization which was dominated by kaolinite. The trend followed for labile C fractions was found to be similar between smectitic+vermiculite clay minerals (Vertisol) and kaolinite+illite mixed clay minerals (Mollisol) followed by Illite dominating minerals (Inceptisol) and kaolinitic clay minerals (Alfisol). Both SSA and CEC of clay followed trend of Vertisol > Mollisol > Inceptisol > Alfisol. The Pearson's correlation matrix showed significant correlation among labile C fractions and clay properties viz., SSA, CEC and clay content (%). This study highlighted those soils with 2:1 expanding/limited expanding clay mineralogy help to sequester labile C in soil.

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Comparison of combinations of cations and anions for exhaustive potassium release from soils

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The objective of our study was to find out the most effective solution for extraction of soil K^+ under successive leaching. We have tested 0.1 N solutions of acetates and chlorides of barium (Ba^{2+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), ammonium (NH_4^+), and hydrogen (H^+) ions, separately for their effectiveness in releasing soil K. Eighteen hours of contact times were given to each soil (1:2.5 soil and solution ratio) for extraction. Ten such extractions were carried out in succession. Surface (0-15 cm) soils of acid Entisol, calcareous Entisol, Alfisol, Vertisol, and Inceptisol were selected for observing K^+ release. More K^+ release was observed from the chloride solution (except NH_4-acetate) because higher cationic dissociation is associated with chloride salts than acetates. Maximum K^+ release was recorded from 0.1 N HCl due to its effect on mineral dissolution, rather than solid-solution exchange due to K^+ gradient. Higher cumulative release from NH_4Cl and CH_3COONH_4 were observed on the initial stage (except Vertisol), followed by a steady reduction in the subsequent extractions due to interlayer collapsing by NH_4^+. However, comparatively higher release in each extraction can be observed from Ba^{2+} ion. The Ba^{2+} has higher exchange capacity and similar hydration energy similar to K+ as compared to rest of the experimental cations. Sodium, magnesium, and calcium have also shown gradual K+ release but the quantities were less as compared to Ba^{2+}. So, we concluded that $BaCl_2$ is the most suitable extractant for exhaustive K^+ release from soil without mineral dissolution under successive leaching condition.

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Clay mineralogy and weathering of soils in different forest ecosystems of the western ghats of Kerala

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Clay minerals are considered as the basis of soil and are formed by the weathering of the parent material. The Western Ghats is a pristine landscape having diverse ecosystems. A study of the origin and transformations of clay minerals in these soils should help us better understand pedogenic processes in the humid tropics. The study was undertaken to find the variations in taxonomy, soil weathering, and pedogenic changes in different forest soils in the Southern Western Ghats of Kerala, India. Four different forest types - shola, dry deciduous, grassland, and eucalyptus plantation were selected for the study. The soil profiles were dug up to 1.5 m and samples were collected horizon-wise from the profiles. The collected samples were used for physical, chemical, mineralogical (X-ray diffraction), morphological (Scanning Electron microscopy), and thermal (Thermo Gravimetric – Differential Thermal) analysis. pH was found acidic in all systems. A high organic carbon percentage was observed in the shola forest (18%) and low in the dry deciduous forest (0.5%). The soils in the different forest systems varied from highly weathered Ultisols to relatively immature Inceptisols. Evaluation of mineral distribution in soils of these forest ecosystems indicated the presence of 2:1 minerals such as smectite, chlorite, mica, gibbsite, feldspar, and quartz, as well as 1:1 minerals like kaolinite. The mineralogical studies revealed that the weathering status of dry deciduous forests was the least weathered and eucalyptus plantation the most weathered soil system. Halloysites were observed in the shola forest indicated restricted weathering in these systems.

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Sub-soil sodicity and mineral induced natural soil degradation in Vertisols of semi-arid central India

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Soil degradation is generally attributed to anthropogenic causes, with the exception of few recent studies elucidating the natural soil degradation in semi-arid tropical (SAT) environments, where the ill effects are more pronounced due to low vegetative cover and increasing aridity. This study highlights the natural soil degradation due to sub-soil sodicity of SAT deep black soils which causes waterlogging. In addition, the pedogenic factors and processes related to presence of palygorskite which further aggravates the waterlogging is also highlighted. We observed low hydraulic properties in some shrink-swell cotton growing soils (Typic Haplustert and Sodic Haplustert) occurring in a similar landscape of Yavatmal district of Maharashtra and investigated the cause of such a phenomenon. The hydraulic properties of these Vertisols are impaired with a saturated hydraulic conductivity (Ks) in the range of 0.1-8 mm hr-1. The exchangeable Ca/Mg ratio of the soils varied from 1.46 to 8.15 in the surface horizons and from 0.73 to 6.23 in sub-surface horizons suggesting increase in Mg^{2+} in the sub-surface layers. The X-ray diffractograms of water dispersible clay indicated the presence of clay size smectite, mica and kaolinite. However, deconvoluted X-ray diffractogram indicates that, instead of any single peak at 1.00 nm, a multiple number of smaller peaks at 1.04, 1.01, and 0.99 nm is visible, which are characteristic peaks of palygorskite mineral. The Mg bearing palygorskite mineral adversely affects the intrinsic soil properties, such as a decrease in Ks (< 10 mm hr^{-1}) and low exchangeable Ca/Mg ratio with pedon depth, and an increase in soil base saturation (> 100 %), which were recorded in these soils. We report the presence of palygorskite, which caused decrease in exchangeable Ca/Mg ratio with soil depth and subsequent reduction in Ks which leads to the soil degradation in the SAT environments.

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Arresting metals contamination in soil plant continuum using clay and lime

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Heavy metals are non-biodegradable and cause severe threat to human and soil environment even at low concentrations, it is inevitably added in soil through wastewater irrigation in peri-urban agriculture. Hence, a field experiment was carried out to reduce the deleterious effect of heavy metals in soil and plant through different amendment viz. lime and bentonite under Cabbage crop (*Brassica oleracea*) at experimental farm of ICAR-Indian Agricultural Research Institute, New Delhi during 2017-18. Crop was irrigated with metal (lead, chromium and nickel) spiked wastewaters containing at 2 and 5 times of their permissible limits. Results reveled that, amendments, lime and bentonite applied plots recorded 40.4 t/ha and 40.7 t/ha cabbage yield respectively. However, significantly higher yield (40-45%) of cabbage was recorded in wastewater irrigated plots as compared to groundwater irrigated plots. Amendments applied plots recorded 58-68%, 40-45% and 25-50% less concentration of Ni, Cr and Pb respectively in cabbage bolls compared to the control plots with no amendments. Lime and bentonite applied plots had lower health risk values compared to the control plots for all the heavy metals (Pb, Ni and Cr). Most importantly, the available Pb, Ni and Cr content of the soil decreased with application of lime and bentonite in soil. The available nitrogen content was low in lime and bentonite amended soil than the control plots. Therefore, these amendments may be used for arresting the transfer of heavy metal in food chain with in-depth study of metals fractions in soil plant continuum.

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Evaluation of functionalized clays for immobilization of arsenic

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Clays are well-known for their excellent metal sorption properties. Unmodified clays capture heavy metals from the polluted environment but they are less effective than modified clay due to the clay's low loading capability, limited binding strength, and poor specificity (McBride, 1994). To immobilize arsenic (As) in contaminated soils, a variety of modified bentonite, kaolinite (Fe-modified and DMSO-modified) and redmud (Fe-modified) were developed. Subsequently, the structure and morphologies of the modified clays and modified redmud were characterized by Fourier transform infrared spectroscopy (FTIR), Specific surface area (SSA), Cation exchange capacity (CEC), X-ray diffraction (XRD), Transmission electron microscopy (TEM) and Scanning electron microscopy (SEM). Adsorption and desorption study of As on modified clays and redmud was carried out under control laboratory condition at different times (15, 30, 60, 90 and 120 mins), temperature (25 and 35 °C) and pH (5.0, 6.2 and 8.0). The clay products achieved equilibrium within 120 mins, according to the kinetic study and were best fitted to the power function and simple Elovich equation. Regardless of the adsorbents used, the quantity of arsenic adsorption in the aqueous solution was substantially lower at pH 8.0 and was highest at pH 6.2. But in case redmud, adsorption was better at pH 5.0. Adsorption isotherm experiments revealed that modified clays and redmud were more effective in removing arsenic than unmodified clays. According to arsenic sorption capability Fe-bentonite, DMSO-bentonite, and Fe-redmud were the best screened products.

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Synthesis and evaluation of novel N fertilizer products involving bentonite clay for improving NUE

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Red and lateritic soils are third most important soil group in the world predominantly occupying semiarid to humid tropical climatic areas. In the present study, five soil pedons were selected along a toposequence from the Eastern Ghats to East Coastal Plains of Tamil Nadu for exploring the significance of climate and landform upon the weathering status and clay activity of soil. One profile each representing Kolli hills and Yercaud hills of Eastern Ghats and three profiles representing Inland Plains of Sivagangai and Thiruvarur district were studied. Results indicated that bulk density values are uniform in different horizons of hilly ranges indicating uniform weathering rates with depth whereas in the Inland Plains it increased with increasing depth. Silt to clay ratios are relatively higher (> 0.15) in the surface horizon and decrease with increasing depth indicating that sub-soil horizons are more weathered than surface horizons except in the Inland Plains of Sivagangai where it ranged from 0.08-0.11 (< 0.15) in the subsoil. The soils of hill ranges are slightly acidic in surface and strongly acidic in subsoils. The pH increased with depth from moderately acidic surface soil to neutral subsoil in Sivaganga. The soils are clayey and clay content increased with depth. The soil of Thiruvarur showed neutral pH in surface and slight to moderately acidic pH in subsurface layer. The CEC is low and base saturation is less than 100. The organic carbon content is high in hill ranges whereas it is low in Inland Plains. The CEC/ Clay ratio ranged from 0.1-0.5 and it is high in the hill ranges (semi active) and low in Inland Plains indicating the presence of sub-active kaolinitic clays. The gravel and plinthite are present in the profile except Thiruvarur, which indicate very short dry period and water table fluctuations.

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Modeling the Adsorption Behavior of Zinc on Bentonite Clay

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Batch experiments were carried to study the effect of pH, initial cation concentration, adsorbent dosage and contact time on the removal of Zinc (Zn) metal from aqueous solutions. Scanning electron microscopy (SEM) and Fourier transform infrared (FTIR) spectroscopy were used to examine the morphology and functional groups present in the adsorbent. Maximum adsorption of the Zn ion could be achieved at pH 9 with the equilibrium time of 20 minutes. The extent of cation removal increased with decrease in the initial concentration of the ion solution and also increased with increase in contact time and amount of bentonite clay dosage. The equilibrium data obtained with optimized conditions were fitted in two parameter isotherm models like, Langmuir and Freundlich, models and the values of their constants were determined. Metal uptake from the aqueous solution on bentonite clay was found to be about 80%. Kinetic modeling for the metal ion adsorption was done using pseudo-first-order, pseudo-second-order and intraparticle diffusion models. It was found that the pseudo-second-order kinetic model most appropriately described the adsorption kinetics with R^2 value of 0.99.

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Modeling the Adsorption of Reactive Black-5 Dye on Bentonite Clay

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Reactive dyes are part of different industries including leather, food and textiles. The colored effluents generated by these industries lead to contamination of fresh water resources. Reactive dyes are difficult to degrade and are carcinogenic in nature. The presence of these dyes in water can cause health hazards to human and aquatic organisms. The study was therefore carried out to explore the potential of bentonite as adsorbent for the removal of reactive black-5 from the simulated aqueous solutions. Batch experiments were carried to study the effect of pH, initial dye concentration, adsorbent dosage and contact time on the removal of dye from simulated dye effluent. Scanning electron microscopy (SEM) and Fourier transform infrared (FTIR) spectroscopy were used to investigate the morphology and functional groups present in the adsorbent. Maximum adsorption of the reactive dye could be achieved at pH 5 with the equilibrium time of 120 minutes. The extent of dye removal increased with decrease in the initial concentration of the dye and also increased with increase in contact time and amount of adsorbent dosage used. The equilibrium data obtained with optimized conditions were fitted in two parameter isotherm models namely, Langmuir, Freundlich, Temkin and DR models and the values of their constants were determined. Freundlich isotherm was found to be best fitted with the experimental data so obtained. Maximum dye uptake of the reactive black-5 on bentonite clay was 1341 µg/g. Kinetic modeling for reactive black-5 adsorption was done using pseudo-first-order, pseudo-second-order and intraparticle diffusion models. It was found that the pseudo-second-order kinetic model most appropriately described the adsorption kinetics with R^2 value of 0.99.

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Characterization of non-conventional vermicomposts and their application for enhancing yield and quality of bell pepper

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Increasing nutrient bioavailability and better soil enzymatic activity by applying vermicompost enhance the fruit yield and various fruit qualities of bell pepper. To test this hypothesis, an experiment was conducted to characterize the vermicompost prepared from non-conventional plant and animal sources and applied these vermicomposts to soils planted with bell pepper, of which most of the sources are non-conventional. We collected samples at the intermediate (40 days) and final (80 days) stage of decomposition. With the advent of time, the total carbon content of the bedding materials decreased and, as a result, the C: N ratio was narrowed down in all final products (5.6-13.3). The Zn, Cu and Mn contents decreased, while the Fe content increased in the final products. The activities of PMEase and dehydrogenase enzymes were reduced by 2.5-26.0% and 15.5-84.1%, respectively, in the final stage, while the activity of â-glucosidase increased by 2.0-30.7% in the final stage. In the pot experiment, application of vermicompost improved the morphological, biochemical and yield attributes, which in turn translated into higher yield and improved quality of the product. Fruit yield per plant was 24.2-157.9% higher than the untreated control in all treated soils. In addition, the vermicompost treated soils exhibited better soil health by increasing soil organic carbon content (2.9-65.9%), available nitrogen (5.1-43.6%), available phosphorus (12.6-56.6%) and available K (13.6-87.9%). We conclude that the properties of mature vermicomposts in terms of major nutrients, enzymes and micronutrients content are mainly determined by the litter material and mainly by the animal excreta. The application of vermicompost increases the quality and yield of green bell pepper and improves soil health. Therefore, in addition to the traditional production of vermicompost from cow dung and rice straw, the production of vermicompost from local wastes can also be promoted.

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Inorganic soil phosphorus mobilization using rice straw and phosphorus solubilizing microbes under varying hydro-thermal regimes in tropical Inceptisol

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To mobilize inorganic phosphorus (P) under varying hydrothermal regimes, an attempt was made by treating soils with varying doses of rice straw (RS) and P solubilizing microbes (PSMs). Six treatments were obtained a) T0 (control: no PSMs and no RS), b) T1 (RS @ 3570 mg kg^{-1} + PSMs), c) T2 (RS @ 4465 mg kg^{-1} + PSMs), d) T3 (RS @ 5355 mg kg^{-1} + PSMs), e) T4 (RS @ 6250 mg kg^{-1} + PSMs) and f) T5 (RS @ 0 mg kg^{-1} + PSMs). They were incubated under four scenarios (S), a) S1: 25°C and 0.033 MPa; b) S2: 35°C and 0.033 MPa, c) S3: 25°C and 1.00 MPa d) S4: 35°C and 1.00 MPa for 90 days. Under S1, soil P availability increased by ~234 and 79% for T3 and T5 over T0. At 0.033 MPa suction, Q10 of organic P mineralization was the highest for T5 and inorganic P solubilisation was the highest for T4. At higher suction (0.1 MPa), Q10 of organic P mineralization was the highest for T5 and inorganic P solubilisation was the highest for T3. Under S2, T3 could reduce Al-P, Fe-P and Ca-P by ~8.9, 33 and 2.5% over T0. Path analysis revealed that inorganic P mobilization was influenced by soil environment (mainly Si) and OAs, whereas, organic P mineralization was impacted by organic acids and soil environment. RS application at 12 and 14 Mg ha^{-1} under sufficient and limited moisture availability, respectively, along with PSMs could enhance P availability.

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Effect of land use on available plant nutrients and microbial activity under four contrasting land use systems in the soils of North Eastern Region of India

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Land use management exerts a tenacious impact on soil nutrient dynamics and biological activity; however, the impact varies with climate, soils, and management practices. In the present study we analysed the soil organic carbon (SOC), available nitrogen (N), phosphorus (as P_2O_5), potassium (K_2O), sulphur (S) and dehydrogenase (DHA) activity in four contrasting land use systems (Forest, Tea, Areca nut and paddy) in 0-15 cm soil depth. Results demonstrated that undisturbed soil under forest had the highest SOC (1.40 %), N (397 kg ha^{-1}), P_2O_5 (95 kg ha^{-1}), S (20.5 mg kg^{-1}) and DHA (237 µg TPF g soil^{-1} h^{-1}) however K_2O (93 kg ha^{-1}) was highest under areca nut plantation. Soil pH varied from 5.3 to 5.6 under different land use system with mean value of 5.3. The study demonstrated that paddy cultivation is degrading more and have a negative impact on soil fertility as indicated by lowest values of SOC, N, P_2O_5, K_2O, S and DHA. Highly managed systems of tea cultivation resulted in lowest value of pH (5.0). It is important to supply balanced nutrients under managed systems for optimum yield and maintaining soil health.

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Adsorption-desorption behaviour of soil phosphorus as affected by conservation agriculture-based maize-mustard system in an Inceptisol

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A detailed study on P transformation under conservation agriculture (CA) based maize-mustard system especially in the soils of upper Indo-Gangetic plains of Inceptisol was undertaken to assess adsorption-desorption behaviour of soil phosphorus (P) as affected by conservation agriculture practices. For this, soil samples were collected after maize harvest from the on-going conservation field experiment started from 2010-11 at ICAR-IARI, Pusa, New Delhi, comprising of the following treatments T1: ZTMZ-ZTM; T2: ZTMZ+BM-ZTM; T3: ZTMZ(+R)- ZTM(+R); T4: ZTMZ(+R)+BM-ZTM(+R); T5: ZTMZ-ZTM-ZTSMB; T6: ZTMZ(+R)- ZTM(+R)-ZTSMB(+R); T7: CTMZ-ZTM; T8: CTMZ-CTM. Adsorption-desorption study revealed that there was a reduction in adsorption capacity in triple zero tillage with residue retention plot when compared to conventional tillage plot. For quantification, P adsorption data were fitted to Freundlich and Langmuir model which showed excellent fit. In Freundlich adsorption isotherm, the parameter 'a' describing adsorption affinity as well as '1/n' describing bonding energy invariably reduced in triple zero tillage with residue retention plot. In Langmuir isotherm, reduction of maximum buffering capacity ascertained T6 as best treatment in terms of P availability to plants with lesser binding capacity. In case of desorption, the soils under different treatments that adsorbed more amount of P were observed to release less amount of P. Desorption index values denoting the hysteresis property of soil under different tillage and residue management options ranged between 0.829 and 0.922, indicating that the adsorption process was reversible and ease of P release from adsorption sites. The findings from this study may be a way forward towards sustainable and balanced nutrient management strategy under conservation agriculture.

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Assessing soil quality under 22 years old long-term experiment with rice-mustard-sesame cropping system in Inceptisol of lower IGP

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Soil degradation is a major threat to agricultural sustainability in India mainly due to intensive cultivation, overuse of chemical fertilizers and agrochemicals. Assessment of soil quality and identification of key indicators are very important for taking necessary rehabilitation measures. The present investigation was undertaken to identify sensitive key soil quality indicators and to develop soil quality indices using data collected from six treatments (control, NPK- recommended doses of fertilizer (RDF), NPKG – 50% RDF + in situ green manuring, NPKGB - 50% RDF + in situ green manuring + biofertilizer@ 10 kg ha^{-1}, NPKF - 50% RDF + FYM@ 7.5 t ha^{-1}, FB - FYM@ 11.25 t ha^{-1} + biofertilizer@ 10 kg ha^{-1}) at 0-15 cm soil depth of ongoing 22 years long-term experiment (1998-2020) under All India Co-ordinated Research Project (AICRP) on Soil Test Crop Response Correlation (STCRC) with rice-mustard-sesame cropping system of Gayeshpur Research Farm of Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal and analyzed for physical (4), chemical (13) and biological properties (15) of soil. Results revealed that 22 years of continuous balanced application of synthetic fertilizers and organic inputs significantly improved physical, chemical and biological properties of soil. For developing soil quality index (SQI) two approaches were followed, conceptual Framework (CF) and principal component analysis (PCA) under both productivity (P) and environmental protection (EP) management goal. The key indicators selected under productivity goal were: total organic carbon (TOC), â-glucosidase activity, available S, available N, urease, amidase activity, mean weight diameter (MWD) and under environmental protection goal were TOC, respiratory quotient (RQ), aryl sulphatase activity, available S, available N, amidase activity, maximum water holding capacity (MWHC) through PCA analysis for their inclusion in Minimum Data Set (MDS). CF based SQI was varied between 0.93-0.68 under productivity goal and 0.93 to 0.64 under environmental protection goal. Meanwhile PCA based SQIs yielded lesser variation than CF based SQIs where PCA-SQI-P and PCA-SQI-EP stretched between 0.95-0.71 and 0.93-0.71, respectively. Both under CF and PCA based SQIs, the greatest soil quality index was obtained under NPKF as well as FB treatments. Therefore, in view of limited availability of organics and yield sustainability, NPKF treatment may be recommended for rice-mustard-sesame cropping system in Inceptisol of lower IGP.

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Tillage and residue management effect on soil properties and crop productivity under different cropping pattern in Haryana

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Effect of tillage and crop residue management on soil properties and crop productivity was evaluated under three cropping systems (pearl millet-wheat, sorghum-wheat and mung bean-wheat) in Haryana, India. Adopting zero tillage practices can enhance soil quality in cropping systems and this study was accompanied by collecting the surface soil samples from prominent pearl millet-wheat, sorghum-wheat and mung bean-wheat cropping system of Haryana state locating in similar agro-ecological regions under two different tillage systems (Conventional tillage and Zero tillage) with the same soil types. The samples were collected from two different depths considered as surface (0-15 cm) and subsurface (15-30 cm) layer. The long-term zero-tillage practices in mung bean-wheat cropping system, resulted, relatively higher soil nitrogen and organic carbon contents, microbial biomass, dehydrogenase, cellulase and urease activities at the 0-15 cm depth than conventional tillage. The abundance of various microbes viz. bacteria and fungi were relatively higher in zero-tillage surface layer in mung bean-wheat crop-rotation. These results indicated that the zero-tillage practices improved physico-chemical as well as microbiological properties of soil that may lead to enhanced crop yield, soil health and productivity as well.

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Effect of inorganic fertilizers, organic manures and biofertilizers on growth and yield of brinjal

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A field experiment was conducted in a sandy clay loam soil with brinjal cv. Annamalai as the test crop in Sivapuri village, Chidambaram taluk, Cuddalore district, Tamil Nadu. The experiment was laid out in randomized block design and replicated three times. The treatments consisted of application of inorganic fertilizers, organic manures and biofertilizers in different combinations. The experimental plots received the fertilizers according to the treatments schedule. The N, P, K fertilizers, FYM, vermicompost and pressmud compost were applied as basal according to the treatments. The growth attributes were recorded on 30 DAT, 60 DAT, 90 DAT and at harvest and yield attributes and fruit yield were recorded at harvest. The results of the experiment clearly revealed that the application of 75% RDF + 7.5 t of FYM ha^{-1} + 4.5 t of pressmud ha^{-1} + 1.5 t of vermicompost compost ha^{-1} + biofertilizers (T9) registered the maximum plant height, number of leaves $plant^{-1}$, number of branches $plant^{-1}$, fruit length, fruit diameter, single fruit weight and fruit yield.

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Temperature sensitivity of soil organic carbon as affected by crop residue and nutrient management options under conservation agriculture

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Conservation agriculture (CA) helps in restoration and accumulation of SOC through minimum mechanical disturbance and CR retention. The present study relates stability of accumulated SOC as affected by temperature under different crop residue (CR) retention and nutrient management options under CA. For this, field experiment was laid in a split-plot design having 3 levels of CR retention in the main plots [no CR retention, 2 t ha^{-1} and 4 t ha^{-1} after harvest of each crop], and three combinations of nitrogen (N) and potassium (K) fertilizer rates [N @ 150 kg ha^{-1} and K @ 0, 30 and 60 kg ha^{-1}] in the sub-plots. Retention of CR significantly affected cumulative C mineralization (Ct) (CR4 > CR2 > CR0) in bulk soil, and macro- and micro-aggregates, irrespective of soil depths (0-5 and 5-15 cm) and incubation temperature regimes (20 °C and 30 °C), whereas different K fertilizer rates did not register any significant effect. Micro-aggregates had higher percentage of total SOC mineralized, decay rate (Kc) and temperature sensitivity (Q10) compared with bulk soil and macro-aggregates, irrespective of temperature regimes and soil depth. Generally, CR4 treatment had lower percentage of total SOC mineralized and K_c compared with that under CR0 treatment for both aggregate fractions, but different K fertilizers did not have any significant effect.

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Effect of engineered biochar on nutrient retention in an Inceptisol

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Biochar can check nutrient leaching, augment soil fertility and sequester carbon in soil. Biochar if produced from crop residue can mitigate the problem of residue burning. Natural biochars have the limitation of low cation exchange capacity (CEC) and anion exchange capacity (AEC). Development of engineered biochar can enhance CEC and AEC simultaneously for higher nutrient retention. In the present study, fourteen engineered biochars were developed by treating the washed rice straw biochar (RBCW) separately with different oxidising and reducing agents to augment CEC and AEC respectively and with their combined treatments to further reinforce CEC and AEC. Then in a screening experiment promising engineered biochars namely RBCW treated with O_3-$FeCl_3$-HCl (RBCOCl), H_2SO_4-HNO_3-$FeCl_3$-HCl (RBCACl), and NaOH-FeOOH (RBCOHFe) were chosen for further characterization and soil leaching-cum retention study. Results indicated that RBCOCl, RBCACl and RBCOHFe recorded considerable increase in CEC and AEC over RBCW. FTIR spectral analysis corroborated the fact. Soil column based leaching-cum retention experiment revealed that all the engineered biochars reduced the leaching of NH_4^+-N, NO_3^--N, P and K and increased their retention from/in a sandy loam Inceptisol (Typic Haplustept). RBCOCl @ 4.46 g kg^{-1} (D2) emerged as the promising soil amendment. Overall, higher dose of biochar application (D2-4.46 g kg^{-1}) was superior over lower dose (D1-2.23 g kg^{-1}). Thus, engineered biochar could enhance nutrient use efficiency, carbon sequestration, reduce the loss of costly chemical fertilizers leading to environmental pollution.

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Effect of oil pollution on soil health

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Indian industrial sector has been developing very rapidly since the last decade. It has seen several economic growth with establishment of special economic zones. Rapid industrial growth also followed by surge in release of toxic effluents in the environment effecting soil and groundwater. Among them oil pollution is one of the most dangerous threats on soil quality effecting agroecosystem of the country. Common causes of oil pollution on soil are mostly anthropogenic in nature such as accidents in agricultural machineries and petroleum storage units or pipelines, unscientific dumping of industrial wastes etc. It can also be caused due to frequent use of petrol/diesel run shallow pumps used in the agricultural fields. Presence of oil in soil changes its physical and chemical properties. Studies on oil contaminated maize (*Zea mays* L.) showed low germination and yield rate. This is attributed to suffocation of plants caused by exclusion of air in soil as oil takes up pore spaces. Addition of crude oil also resulted in increase in microbial activity and Mn content due to the decomposition of hydrocarbons. Solutions for restoration of oil contaminated soil has already been started with heat treatments and chemical leaching but it is a complex process. Bioremediation and phytoremediation have shown results but not in a significant level. Studies are going on for application of physico-chemical remediation but it comes with high cost and chances of secondary pollution.

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Characterization of soil acidity under hilly terrain of the Northwestern Himalayan Region of India

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An attempt was made to study the forms of soil acidity at different soil depths in a catenary sequence under hilly terrain of Lesser Himalayan region in order to understand the effect of pedochemical environment on soil acidity. For this purpose, soil samples were collected from hill top, side slope and valley at three different soil depths in catenary sequences in Almora district of the Northwestern Himalayan region. Results indicated that acidity of soil (both exchangeable- and total potential acidity) on hill top position was found to be significantly higher as compared to that of soils occurring on side slope and valley. High magnitude of total potential acidity in the studied soils may be attributed to the presence of high activity clay minerals in these soils as revealed from the apparent clay CEC (>24 cmol(+)kg^{-1} clay). Significantly higher apparent clay CEC of soil on hill top position as compared to soils occurring on other landform positions indicates more advanced stage of weathering of soil on hill top position. Both the exchangeable- and total potential acidity of soil were found to be significantly correlated with the apparent clay CEC. The study indicates that apparent clay CEC is an important indicator of pedogenesis and soil acidity as well.

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