



From President's Desk



Agrochemicals in agriculture: potential use and concern to minimise adverse impacts on the environment

An agrochemical is defined as a chemical such as a fertilizer, hormone, fungicide, insecticide/pesticide or soil treatment that improves the production of a crop. It is a substance used to manage an agricultural ecosystem. There is a community of organism (microorganisms, plants, animals) in a farming area interacting with the agrochemicals under use.

Effects of agrochemicals use

On one hand, agrochemicals increase plant and animal crop production and on the other hand they cause a lot of damage to the environment. Excess use of chemical fertilizers has led to the contamination of ground-water with nitrate which is poisonous to man and animals in large concentrations. The runoff fertilizers into ponds, streams, lakes and other surface waters can increase algal growth leading to death of fishes and other aquatic animals. Insecticides like DDT remain active in the environment for many years, contaminating all wild life, food grains and surface water including humans. It is now known that millions of wild birds are killed every year in North America due to exposure from agricultural insecticide carbofuran.

Agrochemicals, particularly pesticides, having long persistence in the soil systems severely affect the soil microorganisms, thereby deteriorating the soil health. Amendment of soils with agrochemicals has substantial impact on soil functions and nutrient cycling as well because these chemicals can influence several soil physicochemical properties such as soil moisture, pH, and soil organic carbon. Agrochemicals have a great influence on the shift of microbial population dynamics and communities of soil microorganisms along with many other biotic and abiotic factors ranging from soil characteristics to crop varieties. The use of agrochemicals primarily aims to ensure abundant food supply for humans, but it may have a negative impact on soil biological activity and diversity through direct or indirect actions. However, our knowledge about soil microbial ability to degrade agrochemicals and their influence on microbial diversity in the soil is still limited (Asit Mandal & Madhab Chandra Manna, <https://www.sciencedirect.com/topics/earth-and-planetary-sciences/agrochemical>).

Production trend in India & testing protocols for security

Pesticide production in India is dominated by insecticides and fungicides followed by herbicides and rodenticides. However, the share of insecticides has come down from more than 70 per cent in 2003-04 to 39 per cent in 2016-17. The shares of fungicides, herbicides and rodenticides are growing over the period. The growth in the use of fungicides is high mainly because of their application in fruit and vegetable crops. Major pesticides produced in India are Mancozeb, 2-4-D, Acephate and Profenofos.

There are regulations and procedures for testing pesticides at different stages. The Central Insecticide Laboratory (CIL) is mandated to test the referral samples submitted by any officer or agency of the Central or State Government, while State Pesticide Testing Laboratories (SPTL) mainly test the samples taken at the manufacturing and point-of-sale for quality control. Results of STPLs indicate

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that around 2.5 to 3 per cent of samples tested were misbranded (not as per the label) during 2008-09 to 2012-13. In total, 28 pesticides and four formulations are banned for manufacturing, import and use, eight pesticides are withdrawn, and 13 pesticides are restricted for use in the country. Recently, on the advice of an expert committee, 12 pesticides are completely banned from January 2018 and another six from December 2020 (DAC&FW, 2016) for the largest share in terms of value of exports (28.19%) (http://www.ncap.res.in/upload_files/policy_brief/pb43.pdf).

Export trend from India

In India, total agrochemical exports have contracted by 2% during FY20. India mainly has exported agrochemicals to Brazil (15%), US (10%), Vietnam (6%), Bangladesh (6%), Iran (3%), France (3%) and Indonesia (3%). The trade tensions between the U.S. and China depressed demand for protection products in the U.S., but bolstered its demand in Brazil. Further exports during the month of March fell by 27.1%. International shipments had come to a halt due to the absence of transportation facilities in the last week of March 2020 with respect to the announcement of a nationwide lockdown pan India to contain the outbreak of COVID-19

(<https://www.careratings.com/uploads/newsfiles/Agrochemicals%20Update%20July%202020.pdf>).

Environmental impacts & future potential control measures

Various environmental effects due to agrochemicals have created worldwide concern. Now, the approach is to shift from chemical methods to non-chemical methods of enhancing soil fertility and dealing pests. The alternatives are very expensive and not yet in widespread use. The United Nations Environment Program organised a meeting in the year 2000 and banned the production and use of twelve persistent organic pollutants, especially those used as pesticides. These twelve chemicals have been named as "dirty dozen".

Eight of them are pesticides such as aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex and toxaphene. To control malaria in Africa, DDT has been given special exemption. One hundred and twenty-two nations including USA have accepted the treaty but time will prove how many of them will really implement it

(<https://www.biologydiscussion.com/essay/essay-on-agro-chemicals-and-their-effects/5477>).

From environment consideration in India, bio-pesticides have the potential to control crop losses and reduce negative environmental externalities. Bio-pesticides constitute around 3 per cent of pesticide market in the country. So far 14 bio-pesticides have been registered under the Insecticide Act 1968 in India. Consumption of biopesticides has increased from 219 tonnes in 1996-97 to 683 tonnes in 2000-01, and further to around 3000 tonnes in 2015-16. Studies indicate that use of bio-pesticides in integrated pest management can reduce pesticide use by 66 per cent in cotton and by 45 per cent in cabbage. Thus, biopesticides can play an important role in shifting the focus from chemical pesticides to reliable, sustainable and environment-friendly options. But the pace of development of market for bio-pesticides is not so impressive. Storage of bio-pesticides requires special facilities and skills, which should be developed at all levels in the supply chain. Also, if necessary, fiscal incentives may be provided for production and use of bio-control agents (http://www.ncap.res.in/upload_files/policy_brief/pb43.pdf).

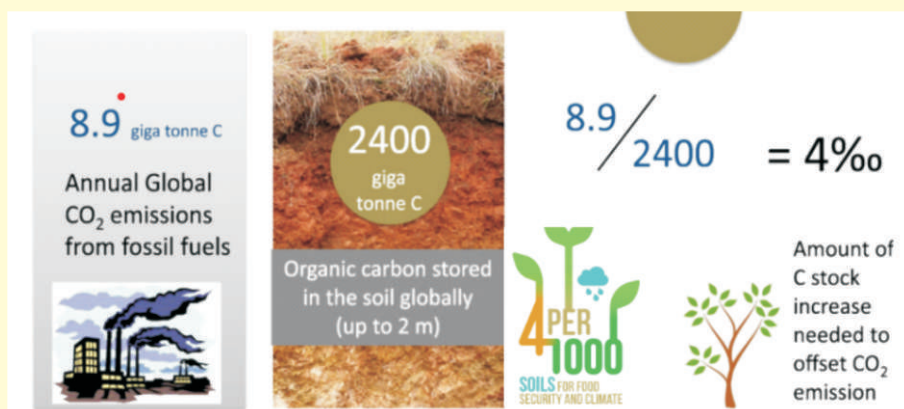
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4 per 1000 initiative

Soils for Food Security and Climate is a global agreement launched by the French Ministry of Agriculture in 2015 in preparation for the Paris climate conference of the United Nations Framework Convention on Climate Change (UNFCCC). The agreement is on the reduction of climate change, limiting global warming to less than 2 Celsius degrees (C°) compared to pre-industrial levels and to pursue efforts to limit the increase to 1.5 C°. In order to keep warming below 2 C°, we need to curb our annual greenhouse gas emission by 8.9 Gt C which is the current annual fossil fuelled C emission in the atmosphere. Alternatively, this could be achieved by proportional increase in soil organic C (SOC) stocks. This is the background of the concept of “4 per mille” for increasing the SOC.

Question may come how does the value '4 per mille' i.e. 0.4% appear. Globally, it is estimated that soil C stock to 2.0 m of soil depth is 2400 Gt and annual fossil fuelled C emission in the atmosphere is 8.9 Gt, as mentioned. Taking the ratio of global anthropogenic C emissions and the total SOC stock (8.9/2400) results in the value of 0.4% or 4‰ (4 per mille). Increasing SOC at the above rate for 20 year period has been proposed to halt the annual increase in CO₂ in the atmosphere and mitigate climate change with an additional benefit of improving soil structure, and other ecosystem functions of soils. However, the '4 per mille' is an ambitious aspiration. Attaining the value in soils is reported to be difficult across the globe. One of the reasons for non-compliance of the concept is that all the land in the globe is not cultivable. Further, retention of C in soil is a function of soil type, its properties and associated climatic factors and varied hugely particularly in arid, semiarid and tropical and sub-tropical regions. This is why it is an aspirational concept for enhancing soil C stock and its associated benefits and be promoted across the globe.



ARTICLES

ARTICLE - 1

Is zinc and iron good cousin in cereals bred over decades since the Green Revolution in India?

The 'Green Revolution (GR)', i.e. the breeding of short-statured, input-responsive, high-yielding crop cultivars (HYVs), has markedly increased grain yield since the mid-1960s and has undoubtedly contributed to alleviating global food shortages and famine (Pingali, 2012). Notwithstanding, there has been debate on whether the GR technologies led to an enlarged prevalence of micronutrient malnutrition in developing countries, since densities of mineral elements in cereal grains have decreased over the last 50 years or so (Fan et al., 2008; Amiri *et al.*, 2015). To alleviate widespread Zn malnutrition in humans, Zn biofortification has been advocated for enriching Zn in the edible parts of food crops (Cakmak, 2008). However, some recent studies suggest that enriching grain Zn concentration with Zn fertilizer had adverse effect on grain Fe accumulation due to a possible antagonism in cereal cultivars (Soleimani, 2012; Saha *et al.*, 2015). On the other side, a few studies also emphasized undesirable effects of Fe application on grain Zn concentration in wheat (Aciksoz *et al.*, 2011; Niyigaba *et al.*, 2019). In this light, we wanted to test whether historical depletion in grain micronutrient density worsened Zn- Fe antagonism, in response to applied Zn and Fe, in some elite, HYVs of rice and wheat released in India, since their birth during GR period.

Therefore, we tested of 16 and 18 most popular cultivars of rice and wheat, respectively in pots for kharif and rabi season of 2018-19 and 2019-20 at Gayeshpur farm (22°58' N, 88°29' E, 9.7 m msl), BCKV developed over decades since Green Revolution in India (Table 1), in response to separate application of Zn and Fe by basal soil (5 kg Zn and 25 kg Fe per ha as zinc sulphate and ammonium iron sulphate), two foliar sprays (0.50% and 0.25%) at maximum tillering and anthesis, and a combination of these two, along with a check. The university soil used for the experiment was high in DTPA-Zn (3.0mg kg⁻¹) and DTPA-Fe (61.0mg kg⁻¹). Rice and wheat plants were grown up to maturity and grains were harvested and analyzed for grain Zn and Fe concentration using an AAS (PinAAcle 900F, Perk in Elmer).

Table 1. Experimental rice and wheat cultivars along with their decade of release since green revolution in India

Decade of release	Rice cultivars (n=16)	Wheat cultivars (n=18)
1960-69	Jaya Pankaj	Sonalika Sharbati Sonora Kalyan Sona
1970-79	IR 8 Swarna Rasi	Kharchia 65 UP 262 WH 147
1980-89	IR 36 Khitish Samba Mahsuri Lalat	LOK 1 HD 2329 HUW 213
1990-99	IR 64 Khandagiri Ranjit Triguna	K 9107 WH 542 PBW 343
2000-09	Naveen Pratikshya Swarna Sub 1	HD 2733 DBW 17 PBW 550
2010-19	----	DPW 621-50 HD 2967 HD 3059

Results showed that grain Zn (represented by dotted line) and Fe (represented by solid line) concentrations are negatively related with cultivar release year in the tested cultivars of rice and wheat (Fig. 1). In rice, for example, grain Zn and Fe concentration dropped to 24% and 19%, respectively from 1960-2009; while in wheat grain Zn and Fe concentration dropped to 30% and 20%, respectively from 1960-2019. However, this depletion cannot be explained by



the notion of dilution effect, since we did not observe any significant variation in grain yield of both cereals from 1960-2019. This depletion could have been manifested by unintended exclusion of favourable traits augmenting their loading into grains, in course of the past breeding processes.

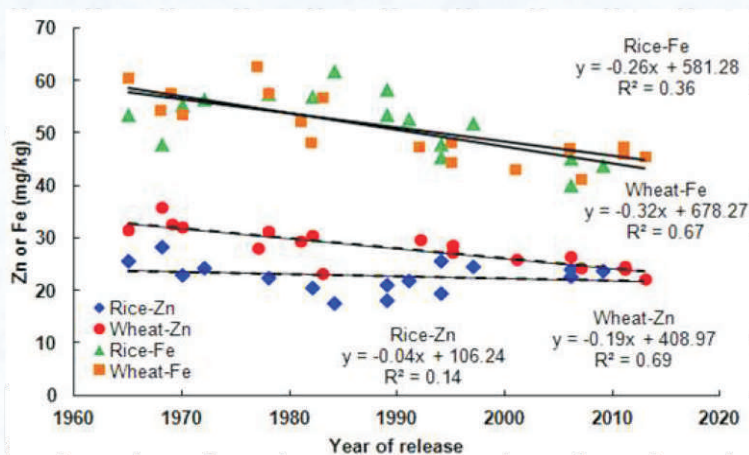
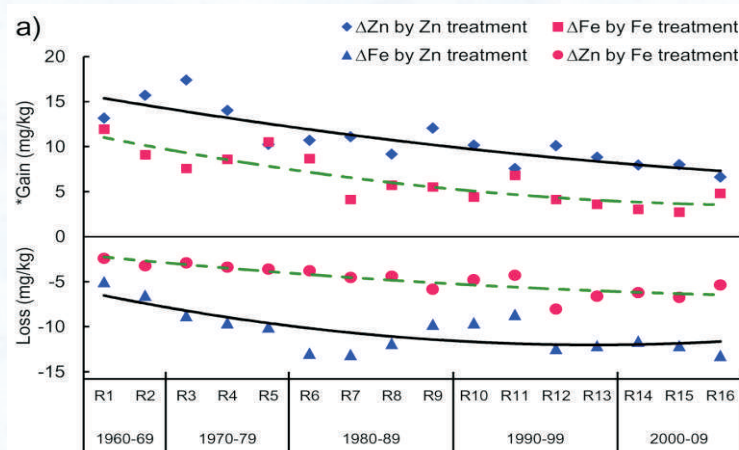


Fig. 1. Relation between native grain Zn and Fe content in the tested rice and wheat cultivars and their release of over time since green revolution in India

From Fig. 2 it was observed that averaged over three different methods of application, Zn as well as Fe response of both cereal cultivars, to external supply of Zn and Fe fertilizers decreased along decadal progression. The magnitude of this decrease to applied Zn and Fe was 9.6 and 13.3, and 10.4 and 8.8% per decade in past more than 50 years in rice and wheat, respectively. Further, it was observed that application of Zn through different protocols had adverse effect (antagonism) on grain Fe accumulation in both cereals, which magnified in the newer released cereal cultivars (Fig. 2). Similar hostile effect of Fe application on grain Zn concentration was also observed in both cereals. The depletion in grain Fe due to applied Zn and vice-versa was to the magnitude of 22.8 and 17.8, and 23.3 and 35.7% per decade in past more than 50 years in rice and wheat, respectively. Such adverse effects were again most intensified when Zn or Fe was applied in a combination of soil and two foliar sprays.

Therefore, this study shows depleting trends in grain density of Zn and Fe in two major staples in past more than 50 years in India. It further suggests a worsened inter-relationship between those elements in the newer-released cereal cultivars developed since green revolution period, which mostly remained unnoticed. We again noticed that, with time, the cultivars became stubborn to external supply of Zn and Fe for enhancing their grain density. These negative effects need to be circumvented by improving the grain ionome in future breeding program.



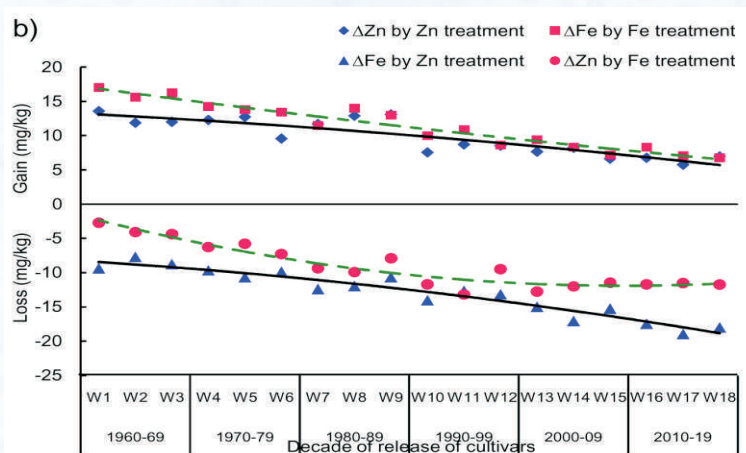


Fig. 2. Quantification of gain in Zn and loss in Fe due to Zn fertilization and gain in Fe and loss in Zn due to Fe fertilization in grains. (a) Rice and (b) Wheat. *Gain in Zn (? Zn, mg/kg)= grain Zn in Zn treated plants – grain Zn in check plants; loss in Fe (? Fe, mg/kg)= grain Fe in Zn treated plants – grain Fe in check plants. Likewise, gain in Fe and loss in Zn in grains due to Fe fertilization was computed.

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**ARTICLE - 2****Arsenic Profiling of irrigation water and rice in Burdwan district, West Bengal**

The problem of arsenic (As) contamination in irrigation water and loading in edible plant parts is one of the most alarming factors thereby risking health for more than 150 million people all over the world. Among different parts of the world where groundwater arsenic contamination and human suffering exist, the magnitude is considered to be, by far, the highest in Bangladesh, followed by West Bengal, India. The occurrence of high arsenic in ground water was first reported in 1978 in West Bengal in India. The most affected areas in West Bengal are on the eastern side of Bhagirathi river in the districts of Maldah, Murshidabad, Nadia, North 24 Parganas and South 24 Parganas and western side of the districts of Howrah, Hooghly and Burdwan.

Arsenic contaminated groundwater is used not only for drinking purpose but also for crop irrigation, particularly for paddy (*Oryza sativa* L.), in south and southeastern Asian countries. Increasing levels of As in agricultural soils from contaminated underground irrigation water, and its uptake in rice, vegetables, and other food crops (Nurchi *et al.*, 2020) have become a real health emergency in this region. To minimize the knowledge gap about As contamination and determine the potential health hazard for local residents, the need was felt to investigate the level of As in soil, water and locally grown rice of Burdwan district. During our investigation, we interviewed farmers of the study area and learnt that they were irrigating their rice fields with arsenic-contaminated groundwater over the past few decades, especially during winter season.

In this investigation As contamination study of irrigation water, soil and tissues of rice were analyzed in selected five blocks viz., Purbasthali I, Purbasthali II, Katwa I, Memari II, Kalna in Burdwan district. Twenty (20) samples each of soil, irrigation water and rice plants were collected from same location from each of five selected blocks during rabi season. Grid-based soil sampling was carried out at 5 x 5 km grid using a hand-held GPS (Garmin GPS 12). The collected soils and water samples were analysed for a few important properties viz., pH, EC and organic carbon (only for soil). In addition, a predictive spatial distribution map was also generated from the analyzed data and respective coordinate-based location in GIS environment for showing areas most at risk. Biological Accumulation Factor (BAF), Translocation Factor (TF) and Hazard Quotient (HQ) were calculated for each sample. A comparison study was also carried out on As status in irrigation water with earlier reports to establish the change in As contamination in the studied districts over past few years.

Result showed that soil pH and irrigation water of different blocks of the district ranged from 7.01 ± 0.119 - 7.61 ± 0.18 and 7.2 ± 0.068 - 7.9 ± 0.075 , respectively. All the selected blocks showed medium organic carbon content (0.63 ± 0.17 - $0.9 \pm 0.1\%$). Electrical conductivity (EC) of the study area for soil and irrigation water ranged from $0.25 \pm 0.03 \text{ dS m}^{-1}$ to $0.3 \pm 0.006 \text{ dS m}^{-1}$, $0.49 \pm 0.14 \text{ dS m}^{-1}$ - $1.02 \pm 0.15 \text{ dS m}^{-1}$. Arsenic concentration of irrigation water in Burdwan district majorly varied in between $0.06 \pm 0.004 \text{ mg L}^{-1}$ and $0.32 \pm 0.17 \text{ mg L}^{-1}$ (Table 1). Arsenic concentration of irrigation water was in the order of Purbasthali II > Purbasthali I > Kalna > Katwa I > Memari II. However, Purbasthali I and Purbasthali II showed wider variability which might have been due to the release of As in natural ground water via co-dissolution of arseniopyrite, stoichiometrically linked to pyrite oxidation (Nurchi *et al.*, 2020). Moreover, less canal irrigation facility, over exploitation of groundwater, multiple cropping with groundwater irrigation, expansion of boro rice cultivation made the As contamination severe in Kalna, Katwa I and Purbasthali I and II blocks (Laha, 2013).

The most of area in Burdwan district pertains to the Ganga-Meghna-Brahmaputra delta of Pleistocene age overlain by Holocene flood plain deposits which is the probable reason of soil As contamination in this district. Continuous irrigation with As rich ground water also increase the soil As level of the study areas. Soil As was found highest in Purbasthali II (3.38 mg kg^{-1}) block followed by Purbasthali I (3.06 mg kg^{-1}) (Table 1). Lower soil As content was found in Memari II (0.86 mg kg^{-1}) and Katwa I (1.8 mg kg^{-1}). The root As concentration varied between $13.13 \pm 1.73 \text{ mg kg}^{-1}$ - $2.9 \pm 0.17 \text{ mg kg}^{-1}$. Whereas, the straw As ranged from $1.82 \pm 0.61 \text{ mg kg}^{-1}$ - $1.04 \pm 0.87 \text{ mg kg}^{-1}$. However, grain samples recorded low As content varied in between $0.002 \pm 0.08 \text{ mg kg}^{-1}$ and $0.40 \pm 0.07 \text{ mg kg}^{-1}$, which is below the permissible limit (1 mg kg^{-1}) by WHO (Fig.1). The grain As loading in different blocks followed the order of Purbasthali II > Purbasthali I > Katwa I > Kalna > Memari II.

The spatial distribution map of As contaminated irrigation water suggested very high variability in all the blocks. (Fig 2. a-e). In Purbasthali II, eastern site of the block showed comparatively deeper colour which interpreted to be high As contaminated category. Whereas, northern site of the block falls in less affected (0.01 - 0.05 mg L^{-1}) category. In the central portion of the block both moderately affected category (0.051 - 0.10 mg L^{-1}) and less affected (0.01 - 0.05 mg L^{-1}) category prevailed.

Even at low concentrations, heavy metals or metalloids may be toxic to plants, animals, and humans if the transfer from soil to plant is high. Reducing the risk of As toxicity to plant and humans requires minimizing uploading of As from soil to

areal parts and lowering the concentration in the edible parts of the crops. The average BAF values of As in paddy soils of Burdwan from soil to root were found to be in the order of Purbasthali I (5.54) > Katwa I (4.54) > Purbasthali II (4.46) > Memari II (3.5) > Kalna (1.79). The transfer factors (TFs) of root to straw (TF_{Root}) values were found in the order of Kalna(0.44) > Memari II(0.36) > Katwa I(0.24) > Purbasthali I(0.17) > Purbasthali II(0.14). The translocation values for straw to grain (TF_{straw}) were found in the following order: Kalna(0.45) > Memari II(0.34) > Purbasthali II(0.24) > Katwa I(0.17) > Purbasthali I(0.04). Hazard Quotient (HQ) is an example model used to analyze human non-carcinogenic risk for local inhabitants. The risk analysis study for Burdwan block conducted through calculation HQ value for rice consumption. Trend of HQ value followed the sequence of Memari II (0.69 ± 0.28) > Kalna (0.87 ± 0.32) > Katwa I (0.87 ± 0.32) > Purbasthali I (1.19 ± 0.42) > Purbasthali II (1.2 ± 0.21).

Table 1 Initial properties of irrigation water and soil of selected blocks of Burdwan district of West Bengal

Blocks (n=20)	Irrigation water				Soil						
	pH		EC (dS m ⁻¹)		pH		EC (dS m ⁻¹)		Organic carbon (%)		
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Purbasthali I	7.9 ± 0.12	6.76-7.80	0.55 ± 0.16	0.19-0.78	7.26 ± 0.054	6.35-7.39	0.28 ± 0.085	0.22-0.31	0.9 ± 0.10	0.41-1.04	
Purbasthali II	7.6 ± 0.009	6.82-7.78	0.67 ± 0.155	0.21-0.89	7.01 ± 0.119	6.49-7.22	0.25 ± 0.03	0.21-0.29	0.77 ± 0.07	0.41-.99	
Katwa I	7.9 ± 0.075	7.03-8.01	1.02 ± 0.15	0.35-1.22	7.14 ± 0.188	7.01-7.28	0.29 ± 0.002	0.27-0.38	0.71 ± 0.07	0.62-0.81	
Memari II	7.2 ± 0.068	7.01-7.52	0.54 ± 0.145	0.19-0.69	7.61 ± 0.18	7.10-8.01	0.30 ± 0.006	0.22-0.32	0.63 ± 0.17	0.48-0.72	
Kalna	7.4 ± 0.061	6.93-7.5	0.49 ± 0.14	0.22-0.56	7.13 ± 0.15	6.89-7.22	0.26 ± 0.01	0.19-0.29	0.93 ± 0.08	0.78-1.01	

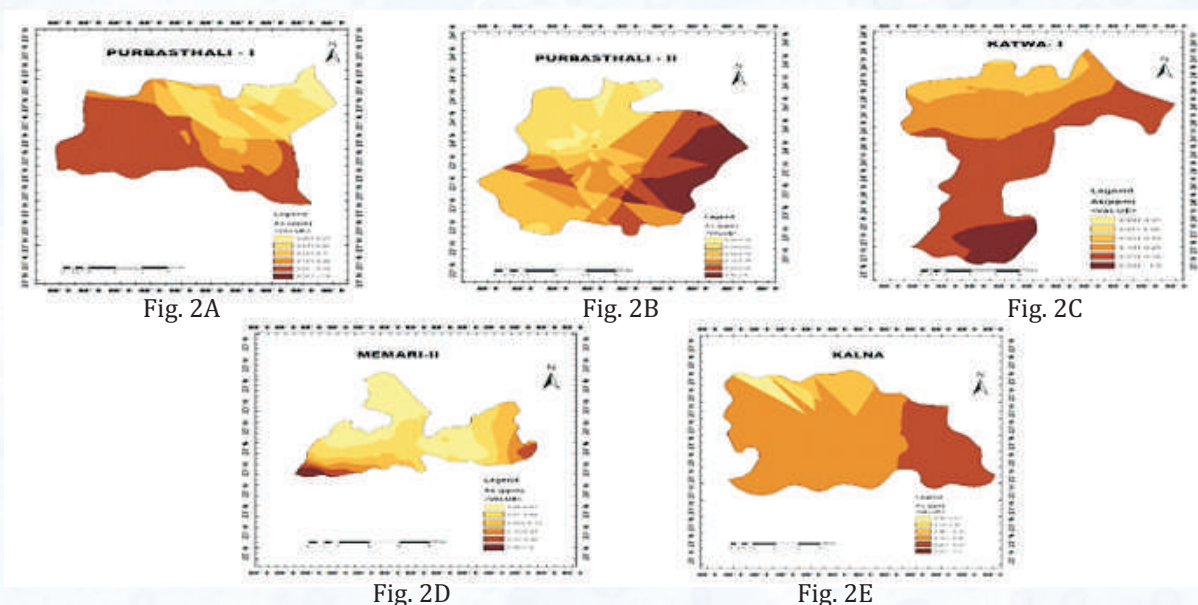


Fig.2 a-e : Spatial distribution Maps showing As of irrigation water (mg L⁻¹) of different blocks of

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**ARTICLE - 3****Role of organics on conversion of crop residue carbon to soil organic carbon**

There is a growing need to increase our understanding of the dynamics of carbon (C) stock in soils and the role that soils may play in the long-term accumulation and sequestration of atmospheric C. This need comes out of the fact that soil is a major reservoir of terrestrial C. It contains as much as 1550 Pg C as soil organic C (SOC) and 950 Pg C as soil inorganic C together constituting about 3.3 times the size of the atmospheric pool and 4.5 times the size of the biotic pool (Lal *et al.* 2004). Suitable crop management to enrich this reservoir through sequestration of atmospheric C to SOC will help to manage global warming significantly and improve the soil health. Crop cultivation is known to influence the distribution and stability of soil aggregates and SOC stock in soils (Zhang *et al.* 2018; Mandal *et al.* 2007). The magnitude of such impact of cropping, however, varies depending upon the climatic conditions, soil type and crop rotation followed (Pathak *et al.* 2011). Because of high temperature, the soils of tropical, subtropical, arid and semiarid regions are expected to be contributing more oxidative products (particularly CO₂) per unit SOC to the atmosphere vis-a-vis the soils of temperate and cooler regions. Again, crop species that are cultivated may also play an important role in maintaining the stock because both quantity and quality of their residues that are returned to the soils vary greatly affecting their turnover or residence time in soil. The information regarding the effects of intensive cultivation with different cropping systems, soil types and their management practices on dynamics of SOC is thus necessary. Once identified, this may lead to evolving suitable agricultural strategies that have great potential to improve SOC stocks and thus attenuate CO₂ loading into the atmosphere and curbing global warming. While cultivating crops, various inputs viz. fertilizers, organics, chemicals, water, tillage, etc. are used, mainly for increasing their economic yield with an attendant increase in the amount of crop residues, a large portion of which is returned into the soils. Therefore, intensive cultivation of crops with these inputs may result in both loss and build-up of C stock in soils. The magnitude of such decline or enhancement of SOC due to continuous cultivation depends on the balance between the loss of C by oxidative forces of tillage operation and the quantity and quality of crop residues that are returned and organics added to the soils.

Studies in the past have shown a build-up of SOC stock under cereal-based cropping system with application of organics [viz. farmyard manure (FYM), rice straw or green manuring] in tropical and subtropical countries. But information regarding the magnitude of such build-up, efficiency of crop-residues and added organic amendments to result such SOC build-up, annual input of crop-residues and/or organics to sustain such SOC build up etc. are very scanty. An attempt has, therefore, been made in this study (i) to determine the impacts of long-term cultivation with different cropping systems and nutrient management practices on SOC, and (ii) to measure the role of added organics and crop residues in SOC sequestration using three long-term fertility experiments in subhumid tropical India with a view to assess their aggrading/degrading influences on C balance in soils for maintaining soil health and curbing global warming.

Three on-going long-term fertility experiments at Pattambi, Jagtial and Udaipur established in 1996 with rice-rice, 2000 with rice-rice and 1996 with maize-wheat cropping systems, respectively were chosen for the study. Pattambi receives an annual rainfall of 2727 mm with 18 to 36°C annual temperature variation; annual rainfall at Jagtial is 750-900 mm with 20.0 to 33.6°C annual temperature variation. Udaipur has a relatively drier climate receiving 636 mm of annual rainfall with 23 to 44°C annual temperature variation. Soils of Pattambi, Jagtial and Udaipur were characterized by sandy loam (Alfisol), clay loam (Inceptisol) and sandy clay loam (Inceptisol) with initial SOC level of 9.0, 7.9 and 8.5 g kg⁻¹ respectively.

Common nutrient management practices in-use to manage the cropping systems were: control, 100%N, 100%NP, 100%NPK, 150%NPK, and 100%NPK+FYM. 100%NPK indicates N:P:K @ 90, 20 and 38 kg ha⁻¹ at Pattambi, 120, 26 and 33 kg ha⁻¹ at Jagtial and 90, 30 and 15 kg ha⁻¹ at Udaipur. Doses of Farm yard manure (FYM) applied with 100%NPK was 5 t ha⁻¹ at Pattambi and 10 t ha⁻¹ at Jagtial and Udaipur. Besides these, additional treatments imposed were 100%NPK+Lime, 50%NPK+FYM, 50%NPK+Green Manure (GM) and 100%NPK+GM at Pattambi; 100%NPK+hand weeding (HW), 100%NPK+Zn, 100%NPK+S and FYM@20 t ha⁻¹ at Jagtial and 100% NPK+Zn, 100% NPK+S, 100% NPK+Zn+S, 100% NPK+Azolla and FYM@20 t ha⁻¹ at Udaipur. For convenience of comparisons, treatments in the present study were grouped into unfertilized (CK), imbalancedly fertilized (BF-), balancedly fertilized (BF), overly fertilized (BF+), integrated nutrient management (INT) and organically fertilized (ORG) soils. Standard practices to raise crops were followed all through the years at all the three sites. Surface soil samples (0-15 cm) were collected in 2018 and were processed and analysed for total SOC, bulk density. Cumulative C input through crop-residues and organics were calculated by standard factors.

Crop management practices significantly influenced total SOC stock at all the three sites. At Pattambi, all nutrient management practices raised the SOC stock by 11 to 83% over the initial status (18.2 Mg ha⁻¹) (Fig 1). The SOC

sequestration with INT was significantly higher than that of BF and BF+ which, in turn, had significantly higher gains over the BF- and CK treatments. Out of 81 to 156 Mg ha⁻¹ of added organic C through crop-residues for 22 years, only 2.5 to 10.6% was converted to SOC with the highest conversion with INT treatment (Fig 2). At Jagtial, the studied treatments caused 9 to 89% gain in SOC stock over the initial status (26.2 Mg ha⁻¹), and all the nutrient management practices differed significantly among themselves. Soils under INT had 41% higher SOC stock than BF. Cumulative C input for 18 years in different treatments ranged between 80 to 188 Mg ha⁻¹ and conversion of added C to SOC was significantly

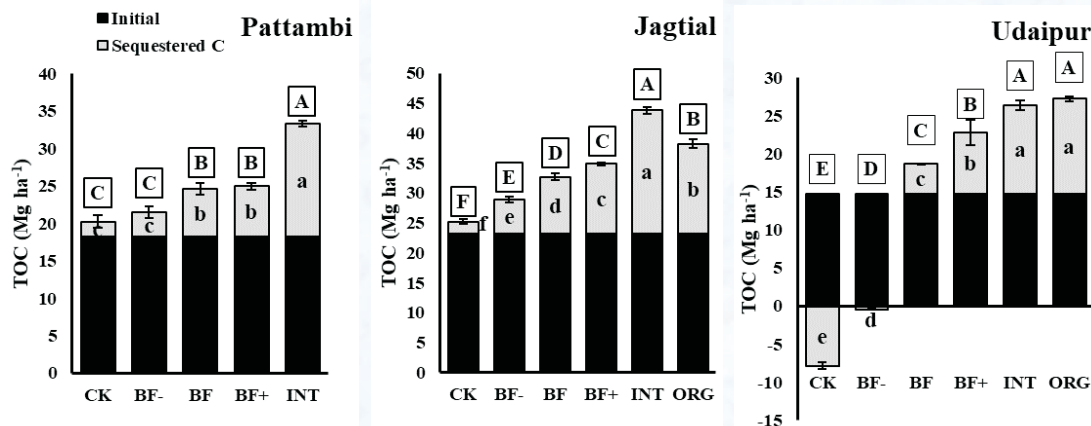


Fig 1. Effect of nutrient management practices on total soil organic C stock at Pattambi, Jagtial and Udaipur after 22, 18 and 22 years, respectively

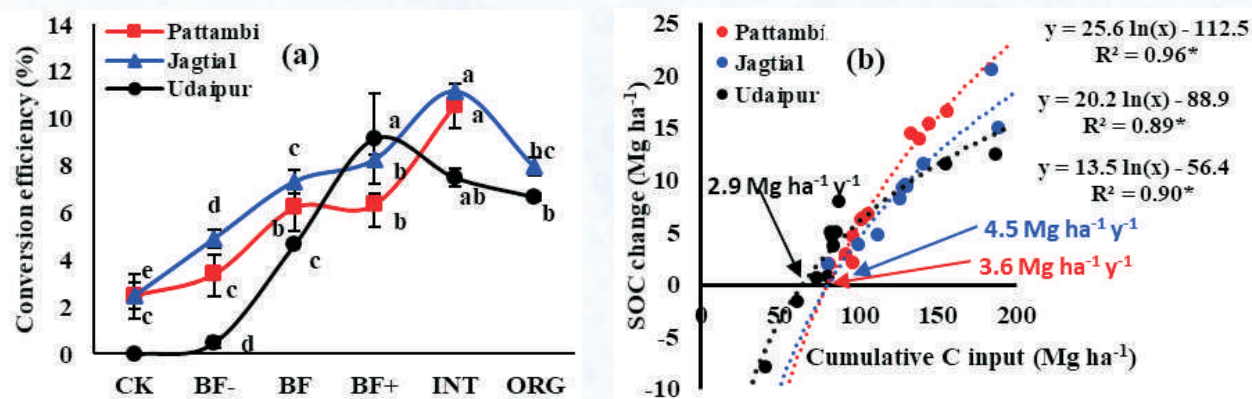


Fig 2. Effect of nutrient management practices on conversion of crop residue C to soil organic C stock at Pattambi, Jagtial and Udaipur after 22, 18 and 22 years, respectively(a) and the relationship between SOC sequestration and cumulative C input (b).

higher with INT (11.2%) followed by other fertilized treatments (4.9 to 8.3%) and CK (2.5%). At Udaipur, CK and BF- caused 3 to 53% decline in SOC stock; however, BF, BF+, INT and ORG caused significant gains (26, 54, 78 and 84%, respectively) in SOC stock. Out of 40 to 187 Mg added C ha⁻¹ either through crop-residues or externally added organics for 22 years, only 0.5 to 9.1% was stabilized to SOC, and the stabilization was significantly higher with INT and BF+ (7.5 to 9.1%) than the other treatments. At all sites, SOC sequestration was logarithmically related to the cumulative C input to soil. The critical amount of C inputs needed to add every year to sustain soils antecedent SOC stock was 3.6, 4.5 and 2.9 Mg ha⁻¹ at Pattambi, Jagtial and Udaipur, respectively (Fig 2).

At all the three sites, cropping with balanced fertilization increased SOC stock in soil. An increased crop-residue C input in soil with NPK because of increased biomass yield was the possible reason for this increase. Loss of C from soil due to oxidative forces of ploughing for cultivation was more than compensated for by the increased addition of crop residue C inputs into soil. Cropping with integrated nutrient management showed a further increase in SOC stock over the balancedly fertilized soils. This was obviously associated with the applied C through the organics and a large amount of plant residues and root biomass C left over in the soils owing to increased yield under the treatments. Similar buildup of SOC stock due to inclusion of legumes in crop rotation in addition to manure and fertilizer had also been reported from results of long-term experimentation (Qaswar *et al.* 2020; Berhane *et al.* 2020). Higher conversion of added C in



integrated nutrient management practices might be due to formation of stable complexes with cellulose, lignin and polyphenol present in the added organics and the proteins of plant origin. Application of organics may thus enhance the conversion of crop residues C (stubble-C, root-C, exudate-C etc.) to SOC by 2.9 to 4.4%.

Application of organics along with inorganic fertilizers had cause significantly higher stabilization of added C into the soil than that caused by the imbalanced, balanced or over fertilization treatments irrespective of soil type, climatic condition and cropping system involved.

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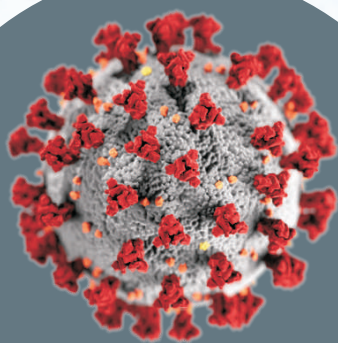
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“As crude a weapon as the cave man's club, the chemical barrage has been hurled against the fabric of life - a fabric on the one hand delicate and destructible, on the other miraculously tough and resilient, and capable of striking back in unexpected ways. These extraordinary capacities of life have been ignored by the practitioners of chemical control who have brought to their task no "high-minded orientation," no humility before the vast forces with which they tamper.”

? **Rachel Carson, Silent Spring**



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