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Society for Fertilizers and Environment
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From President's Desk

Research focus on soil, water and fertilizer practices under changing climate

Having dealt by far specific research areas of environment related aspects over the last nine issues it is decided for the current volume to discuss comprehensively the impacts and roles of three major and interacting domains affecting farming in relation to climate change, and suggest future research needs to combat the progressively declining scenario of the former especially in the context of India.

In India, 17.5% of global population resides in only 2.4% land mass supported by 4% of fresh water resources. Besides, about 5 billion tonnes of soil is washed away every year taking away with it nearly 6 million tonnes of nutrients due to poor soil and water management practices. Emphasis on application of major nutrients has triggered widespread deficiencies of secondary and micronutrients like sulphur (41%), zinc (49%), boron (33%) with other micronutrients, e.g. iron, copper, manganese, molybdenum, etc. The water scenario is equally gruesome. Per capita availability of water has radically reduced from over 5000 m^3 in the 50's to a meagre 1656 m^3 in 2007 and is speculated to be well less than the internationally prescribed level (1700 m^3) to 1140 m^3 by 2050. Currently almost 80% of this water is generally allocated to agriculture, but in all likelihood, it could be cut down by 10-15% due to challenges from other sectors like domestic, industry, power, etc. Having considered all these, crop production is surmised to increase at a rate of 4% in the coming decades which is only possible if we are able to manage our soil and water judiciously in the face of changing climate-induced soil and water ecology, the latter alone is most alarming to the society and possibly an irreversible process.

Earth's temperature is on the rise, as evident from the 11 warmest years out of 12 years between 1995 and 2006 with 0.74°C increase recorded between 1906 and 2005. Increased level of greenhouse gases (GHG), such as carbon dioxide, nitrous oxide, methane and carbon monoxide, has led to the global warming. Projected scenarios of global warming indicate that the global average surface temperature could rise by 0.3 to 6.4°C by 2100. Uncontrolled human activities, such as irrational agriculture, burning of fossil fuels, changed land use patterns and related practices are among the major sources of GHGs. Worldwide, the net effect of climate change will be to decrease stocks of organic carbon (C) in soils, thus releasing additional carbon dioxide (CO_2) into the atmosphere and acting as a positive feedback, further accelerating climate change. Soil managers, therefore, are ordained with the dual task of chalking up adaptation measures for maintaining organic carbon stock on one hand and formulate practices that would not furtherance climate change while water managers have to devise adept policies to secure water for food security in the face of global warming-induced water scarcity in near and distant future.

CONTENTS

Future research needs towards adaptation and mitigation for fostering productivity against climate change

Climate modelling

- GCMs should be carefully devised for each agro-ecological zones.

Soil & Fertilizer

- Soil carbon being the single most important crop growth parameter, simulation studies on soil carbon dynamics in enhanced GHG scenarios need to be done.
- Change in other nutrient dynamics should be studied with greater precision, say using isotopic techniques.
- More effective techniques for sequestering soil carbon need to be devised.
- Social, economic and environmental suitability of diversification with bio-energy crops should be properly assessed.
- Economic feasibility and social acceptability of organic farming systems should be assessed.
- Focus on monitoring soil properties should be applied in terms of soil health; and GoI should introduce 'soil health card' in place of 'soil fertility card' as currently under practice.
- Increasing fertilizer use efficiency
- Arresting soil erosion
- Land restoration and land use changes

Water

- There is a mismatch between the large-scale models on climate and catchment, which needs further resolution.
- Impacts of changes in climate variability need to be integrated into impact modelling efforts on hydrology and water management, with apprehension for decreasing reliability especially of the hydro-power dependency of irrigation planning in national and state sectors.
- Improvements in coupling climate models with the land-use change, including vegetation change and anthropogenic activities including irrigation and water management, are necessary.
- Climate change impacts on water quality are poorly understood. There is a strong need for enhancing research in this area.
- Despite its significance, groundwater has received little attention from climate change impact assessments, compared to surface water resources, which should be re-enforced.
- Water resources management clearly impacts on many other policy areas (e.g., energy projections, nature conservation, etc.). Hence there is an opportunity to align adaptation measures across different sectors.

In this issue, the theme areas of soil, fertilizer and water management practices and future research needs for sustainable agriculture and environment have been included. Paradigm shift in fertilizer technologies and their efficient use from the points of view of increasing productivity with higher nutrient use efficiency, improved soil health, alongside restoration of the environment have been proposed. Use of rice straw burning, its impact on environment, and alternative measures to mitigate adverse effect are also discussed.

HSSen
President

NEWS

Sixth Annual Convention and National Seminar of the Society

Date: 27th March, 2019

Venue: Farmers' Academy and Convention Centre (Lake Hall), BCKV, Kalyani

The 6th Annual Convention and National Seminar on "Use of agrochemicals for a sustainable agriculture and environment" was organized by the Society in collaboration with Bidhan Chandra Krishi participated by 180 academicians, scientists, professionals, researchers and students from Universities, Research Institutes, KVKs, and Industries.

The 3rd Foundation Lecture was delivered by Dr. C.L. Acharya, Former Director ICAR-IISS, Bhopal and Former Director Extension Education, HPAU, Palampur on ***"Efficient soil, water and fertilizer nutrients management: must for sustainable agriculture and environment",*** where he deliberated upon present scenario of soil degradation and water pollution in India, which induces poor soil fertility and lower water use efficiency for crop production.

The 1st Dr. N.P. Datta Memorial Lecture was delivered by Dr. A.K. Singh, Secretary, NAAS, New Delhi and Former DDG (NRM), ICAR & Vice-Chancellor, RVSKVV, Gwalior on ***"Need for a paradigm shift in fertilizer management in India"*** where he articulated possible natural resource management interventions to attain sustainable development goals.

Also, there were three special lectures delivered by Dr. T.J. Purakayastha, IARI, New Delhi on ***"Development of smart fertilizers for sustainable agriculture and environment"***, Dr. D.R. Biswas, IARI, New Delhi on "Development of novel fertilizer formulations: a step towards sustainable P management", and by Dr. A.M. Ahire, Head, Field Research and Training, Aries Agro Limited on "Impact of fertilizer use on the environment and future advancement of the technology".

Also, in the seminar one session on competitive oral presentations by young researchers and poster presentation was conducted. Amrita Dasgupta of BCKV ranked first for her presentation on ***"Better together: plant growth promoting microbial consortium for acid soils"***. Anannya Banerjee of IAS, Kolkata was 2nd for her presentation on **"Characterization of potential salt tolerant bacterial bioinoculum from the rhizosphere of *Suaedanudiflora* in Sundarbans"** while Anwesha Mandal and Kabita Chowdhury of BCKV were joint 3rd for their presentations on **"Socialization of soil health management practices: myth vs reality in Hooghly District of West Bengal"** and **"Soil aggregate stability and aggregate associated C, N and P as affected by different cropping systems in comparison to a permanent fallow"**, respectively.

For the posters, ***"Preparation of fertility map for major nutrients by GIS technique: a tool to guide safe use of fertilizers"*** by Biswabara Sahu and A.K. Ghosh, ***"Agrochemicals used in farming and its health and environmental implication in rural setting in Eastern Bankura, West Bengal"*** by Moumita Dey (Gupta), Kalyan Mitra and F.H. Rahman and ***"Effect of micronutrients on growth, yield and quality of strawberry (Fragaria × ananassa Duch.) cv. winter dawn in the Gangetic alluvial region of West Bengal"*** by Tanushree Saha, Bikash Ghosh, Sanjit Debnath, Ajoy Bhattacharjee were adjudged 1st, 2nd and 3rd, respectively.

Annual General Meeting

Date: March 27, 2019

Venue: Farmers' Academy and Convention Centre (Lake Hall), BCKV, Kalyani

After thorough deliberations and discussion following resolutions were taken in the AGM,

1. The proceedings of AGM held on 29 March 2018 were accepted.
2. Annual Report of the year 2018-19 was accepted and approved.
3. The audited statement of Accounts of the year 2017-2018 was revealed to all and was unanimously accepted.
4. The prospect of publishing an e-Journal was discussed and selected members were entrusted to chalk out a plan for the same.
5. The previous EC including the President, Vice-President, Secretary, treasurer and other EC members were re-elected unanimously for another term of next three years commencing from 2019-20.
6. The EC re-appointed the present Auditor for the year 2018-19, which was approved by the house.
7. M/S Bhattacharjee, Dasgupta and Sarma
   Chartered Accountants
   1st Floor, P-700, Block P
   New Alipore, Kolkata - 700053

Articles

Article-1

Efficient soil, water and fertilizer nutrients management: must for sustainable agriculture and environment[1]

All the strategies of efficient water management are soil specific and soil properties, especially the soil-water relations play a very significant role in determining the inputs use efficiency. Soil-water relations are expressed in terms of ability of the soil to retain, release and transmit water within and across the soil system to the atmosphere. The extent of run-off and erosion that erode the capacity of soil to contain and sustain life are indirectly related to soil-water relations. Similarly, the availability and movement of nutrients, processes of salinization and alkalization are directly or indirectly influenced by soil- water relations since the soluble salts move with water. The knowledge of these relations, therefore, is important for better understanding of the soil-plant-atmosphere continuum so as to devise efficient soil-water-nutrient management practices for higher inputs use efficiency and sustainable crop yields.

The other important attributes of soil health being the chemical and biological and all the three components viz., physical, chemical and biological determine the yield and quality of the produce. Soil organic carbon is the single index that governs/maintains the soil physical, chemical and biological health, imparts resilience and curbs global warming, ensuring food security and hence to be maintained at a higher level depending on the soil characteristics and climatic factors.

An overview

Acharya *et al*. (1988) from *in-situ* and laboratory study with undisturbed samples from long term fertilizer experiments (LTFE) after 13 years of continuous cropping of maize-wheat at Palampur reported that the treatment receiving FYM + 100% of the recommended NPK improved the structural index, infiltration rate, water-retention characteristics, organic carbon content, available N, P, and K status of the soil and gave significantly higher crop yield than the other treatments. This treatment out-yielded the one that received 150% of the recommended dose of NPK, indicating the significant positive role of FYM application in improving the overall soil environment. Continuous N application and control treatments considerably deteriorated the soil physical and chemical properties, but P+N improved these properties and significantly increased the crop yield compared with N alone; the trends still persisting even after more than 50 years of continuous cropping at different centers of LTFE (Singh and Wanjari, 2017).

Annual soil loss rate in our country is about 15.35 tonnes per hectare, resulting in loss of 5.37 to 8.4 million tonnes (Mt) of nutrients, reduction in crop productivity, occurrence of floods/droughts, reduction in reservoir capacity (1 to 2% annually), and loss of biodiversity (Sharda and Ojasvi, 2016). Loss of crop productivity, one of many negative impacts of soil erosion by water, has serious consequences for country's food, livelihood and environmental security. Major rainfed crops in India suffer an annual production loss of 13.4 Mt due to water erosion which amounts to a loss of Rs. 205.32 billion in monetary terms (Sharda and Dogra, 2013). Similarly, around 1.07 Mha area is under physical degradation; mostly waterlogging due to permanent surface inundation (0.88 Mha) and about 12.53 Mha of rainfed Vertisols remain fallow due to temporary water logging during *kharif* (NAAS, 2010). Waterlogging alone results in annual loss of 1.2 to 6.0 Mt of grain in India (Bradon and Kishore, 1995).

About 20,000 ha of fertile land are being converted into wasteland of poor soil health every year in different parts of the country for brick making for various kinds of construction work. This amounts to the loss of 540 million tonnes per year of fertile soil.

Soil toxification through chemicals is increasing with greater urbanization. A study at the Indian Institute of Soil Science, Bhopal indicated high concentration of heavy metals (Cd, Cr, Cu, Pb, Ni and Zn) in composts manufactured in many cities of India from mixed municipal solid wastes. These heavy metals may accumulate in soil with repeated applications. In India, soils of about 59, 36 and 5% area are low, medium, high in available N, respectively. Similarly, soils of about 49, 45 and 6 percent area are low, medium and high in available P, respectively; and soils of around 9, 39 and 52% area are low, medium and high in available K, respectively (Chaudhari *et al*., 2015). There is a growing evidence of increasing responses to S for oilseeds, pulses and legumes and high-yielding cereals. Soil analysis and crop response data generated by the TSI-FAI-IFA project during 1997-2006 re-enforced the finding of the AICRP (All India Coordinated Research Project) data of ICAR system based on reported results. Out of over 49,000 soil samples analyzed across 18 states, 46% of samples were deficient in sulphur and another 30% were medium in available sulphur which could be considered as potentially sulphur deficient.

The micronutrient deficiency in crops is growing rapidly both in extent and intensity and as per assessment made under All India Coordinated Research Project on 'Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants' nearly 49, 15, 6, 8, 11 and 33% samples were found to be deficient in zinc, iron, manganese, copper, molybdenum and boron, respectively, across the country and hence all contribute towards poor soil health (Shukla *et al*., 2012).

[1]Third Foundation Lecture of Society for Fertilizers and Environment delivered on 27 March, 2019 at BCKV, Kalyani, West Bengal

The current gap between annual drain of nutrients from the soil and inputs from external sources is 10 million tonnes, which is likely to grow further. This is one of the major causes of soil chemical degradation resulting in poor soil health. However, on the input side there is large disparity in fertilizer consumption across Indian states. In the west zones of the country, the fertilizer input of NPK, being 95.9 $kgha^{-1}$ is much lower than the national average (141.9 $kgha^{-1}$). These figures for east, north and south zones are 140.9, 182.4 and 186.2 $kgha^{-1}$, respectively (Fertilizer Statistics FAI, 2017). Further, out of 565 districts surveyed for fertilizer consumption 93 districts consume <50 $kgha^{-1}$ and another 124 districts fall in the category of 50-100 $kgha^{-1}$ NPK consumption. Lack of assured water supply for irrigation is one of the major reasons for low fertilizer input. Only 109 districts in the country consume fertilizer NPK > 200 $kgha^{-1}$. In Punjab, where more than 98% of the area is irrigated, 19 out of 20 districts surveyed consume fertilizer NPK > 200 $kgha^{-1}$. Thus, Indian agriculture is operating as a net negative balance of plant nutrients resulting in chemical degradation and poor soil health.

The crop response to fertilizer which was about 19 kg during the 60's has come down to 6-7 kg grain per kg N+ P_2O_5+K_2O (Acharya, 2002). The use efficiency of applied nutrients, especially of nitrogen, is quite low, being only 30-40 % in rice, 21-45 % in maize and 45-50 % in wheat. Partial factor productivity of fertilizer N in cereal production in India has declined from 91.1 $kgha^{-1}$ in 1970-71 to 21.3 $kgha^{-1}$ in 2005-06 (NAAS, 2012). In case of phosphatic fertilizer, recovery varies from 15-20 %. While only 54 $kgha^{-1}$ NPK was required to produce 2tha^{-1} in 1970, around 218 $kgha^{-1}$ are being added presently to sustain the same yield (Sharma, 2008). This trend in NPK response is further conjugated with other nutrient deficiencies/ imbalances resulting in falling crop yield with time.

Technological interventions for efficient soil, fertilizer nutrients, and water management

Balanced and integrated nutrient management

The Indian soils, in general, are poor in fertility and continuous cropping. It is, therefore, essential that the nutrients extracted due to continuous cropping are replenished to maintain soil health for sustainable crop production. The Long Term Fertilizer Experiments (LTFE) running since 1972 in different parts of the country have established that balanced use of fertilizer maintained higher soil organic matter status and hence soil health and higher use efficiency than its imbalanced use. Similarly, the integrated nutrient management (INM) which envisages use of chemical fertilizer in conjunction with organic manure, legumes, bio-fertilizer and locally available materials are producing higher and sustainable yields and thereby higher nutrient use efficiency, of both applied and native soil nutrients (Acharya and Sharma, 2007), and wards off the ill-effects of imbalanced fertilizer use and overuse of nitrogen alone (Singh and Wanjari, 2017). Thus, there are less volatilization and other losses of nitrogen into the atmosphere which along with CO_2 emissions is the major cause of global warming. Also, the INM system not only restores, maintains, but also improves the physical (Acharya *et al*., 1988; Singh and Sarkar, 1998), chemical (Sharma *et al*., 1998) and biological (Manna *et al*., 1996; Acharya *et al*., 1998; Sharma *et al*., 1998) attributes of soil quality. The organic source of nutrient in the INM system acts as slow release fertilizer as it synchronizes the nutrient demand set by plants, both in time and space, with supply of nutrients from the labile soil nutrient and applied nutrient pools (Acharya and Bandyopadhyay, 2002).

Water conservation

Rainfed areas

The demand for food would continue to rise necessitating higher productivity from rainfed regions (2 t ha^{-1}). Rainwater, the most crucial input in this region must be harvested properly either *in-situ* through land configuration, tillage, mulching, etc. or *ex-situ* through watershed management, and should be used in most efficient manner.

In-situ rainwater conservation

A. Land configuration: The strategy for *in-situ* moisture conservation can be achieved with the help of summer or off-season tillage, deep ploughing, profile modification, mulching, conservation tillage, vertical mulching or by keeping the soil surface rough.

B. Tillage/Conservation tillage: The effects of tillage on soil properties are often soil, climate and crop specific. Conservation tillage with retention of residue layer on the soil surface is a viable option to crop residue burning as it checks the negative factors causing soil physical, chemical and biological degradation and environmental pollution (Acharya and Bandyopadhyay, 2019). Conservation tillage is also an economical viable alternative to reduce soil erosion on sloping lands which increases organic matter over time and reduces fertilizer N inputs (Acharya *et al*., 1993) and thus it helps maintaining soil health. Conservation tillage practice normally stores more plant available moisture than the conventional inversion tillage practice when other factors are same. The higher retention of soil moisture content under conservation tillage is due to improved soil structure, increase in infiltration of rainwater as crop residue reduces the speed of runoff water and decrease in evaporation loss as surface crop residues act like a mulch cover (Acharya and Bandyopadhyay, 2019). Increase in the available water content under conservation tillage increases the consumptive use of water by crops and hence improves the water use efficiency.

Spreading tender twigs of *Lantana camara* (a wildly growing weed, having no fodder value, causing menace in grass and forest lands) at recession of monsoon rains during the month of September in between rows of standing maize crop conserved sufficient moisture for timely sowing of rainfed wheat (Acharya and Kapur, 1993). The practice not only conserved adequate moisture for timely sowing of wheat and produced higher crop yields but also contributed 30-40 kg of fertilizer N to wheat through decomposition of these tender twigs. Superiority of conservation tillage over the conventional tillage with respect to grain yield of wheat was more pronounced at 60 kg Nha^{-1} than at 120 kg Nha^{-1}. This shows that moisture conserved under conservation tillage was just optimum for more efficient N utilization at 60 kg Nha^{-1} than at 120 kg Nha^{-1} because of strong N and water interaction.

C. Mulching: Mulching and organic residue incorporation contributes to the conservation of soil and rainwater. Mulching also helps in improving the soil hydro-thermal regime and thereby favourably modifies soil biological activity resulting in improved soil fertility and better soil physical environment (Prihar, 2000; Acharya *et al.*, 2018). Relatively small amounts of residues may be effective in enhancing the infiltration and reducing runoff but larger amounts are required to significantly cut down evaporation loss. Acharya and Kapur (2001) reported that (Table 1) application of pine needle mulch @ 10 tha^{-1} at the time of sowing of potato in a shallow depth of silty clay loam soil significantly improved tuber yield and WUE, and resulted in saving of one irrigation equivalent to 40 mm. Application of pine needle mulch proved effective through favourably modifying the soil hydro-thermal regime, and saved water and N consumption without sacrificing yield, and thereby enhanced WUE and NUE.

Ex-situ rainwater harvesting: On an average, 24 M ha-m of the total 400 M ha-m of precipitation received annually in India is estimated to be available as harvestable runoff through on-farm water harvesting (Katyal, 1997). The SAT region falling in 500-1000 mm rainfall zone have a harvestable runoff of 5.54 M ha-m. The benefits accruing from supplemental irrigation from stored

Table 1. Tuber yield and water use efficiency of potato as influenced by mulching and N application (pooled over 4 years)

Treatment*	Autumn Potato		Spring Potato	
	Yield (t/ha)	Water-use efficiency (kg/ha-cm)	Yield (t/ha)	Water-use efficiency (kg/ha-cm)
N 60 kg/kg	8.46	479.9	13.30	257.0
N 120 kg/ha	9.86	528.2	15.15	271.2
Pine needle mulch @10tonne/ha +N 60 kg/ha	12.69	711.0	16.33	340.9
Pine needle mulch @10tonne/ha +N 120 kg/ha	14.52	735.5	18.34	395.4
CD (P=0.05)	1.19		1.46	

*All the treatments received a uniform dose of farmyard manure@ 20 tonne/ha
Source: Acharya *et al.* (2001)

water are manifold. Sharma *et al.* (2010) have reported that additional 9-10 million tones of food grains can be produced by providing one supplementary irrigation from this harvested water.

The *ex-situ* rainfall harvesting technology is highly location specific. In hilly and mountainous regions sufficient intra-terrace water can be harvested and stored on sloping lands in small water harvesting tanks lined with LDPE film overlaid with bricks/stones for growing vegetables/cash crops in about $400m^2$ or for providing pre-sowing/protected irrigation in the absence of rains (Acharya and Kapur, 1997).

Irrigated areas

It is important to save every drop of water and enhance water use efficiency. Over-exploitation of ground water resources in the tube well irrigated area for rice –wheat system is reported to cause a decline in water level of 0.5 metre in Punjab and 0.6-0.7 metre in Haryana annually. Hira (2005) reported that in Punjab on an average the water table fall increased from 18 cm per year in 1982-87 to 74 cm per year in 2004-05. In addition to the decline in water table, the ground water quality is a matter of serious concern. It is affected by arsenic, iron, fluoride content, fertilizer and pesticides use, and saline water intrusion in the coastal areas. Returns from available water resources can be increased and its soil degrading effect reduced through its conjunctive use from different sources. Even conjunctive use of saline water and canal water can be effective in avoiding its deleterious effect. Judging from the trends it can be surmised that water quality will become most constraint in future and agriculture may have to use more marginal quality waters.

Increasing Water use efficiency

It is possible to increase the WUE to 60% with the adoption of water use efficiency technologies. Pressurised and non-pressurised irrigation systems have the potential to increase yield and input use efficiency besides 20-50% water and 10-20% nitrogen saving (Table 2). Using technologies such as sprinkler irrigation and drip irrigation~~, a~~ WUE of 85 to 95% can be obtained. Crops like rice and sugarcane are biggest claimants of irrigation water. Unless steps are taken to regionalize cropping system and water management practices and charges for water use on volume basis are adopted, the increase in water use efficiency and equitable distribution cannot be ensured. The integrated effect of common management practices such as soil wetting, balanced fertilizer application, tillage and mulching can produce synergistic effect on crop productivity and water use efficiency.

Table 2. Comparison of water use, water saving, input use efficiency (WUE & NUE) and relative benefits of different pressurized and non-pressurized irrigation system

Irrigation Method	Yield (t/ha)	Water use (cm)	N use (kg/ha)	WUE (kg/ha-cm)	NUE (kg grain /kg-N)	Water saving (%)	Nitrogen saving (%)
Surface	98	250	225	392	435	--	--
Micro sprinkler	175	155	200	1129	875	38	10
Mini sprinkler	178	170	200	1047	890	32	10
OH sprinkler	169	180	200	939	845	28	10
Drip	190	150	200	1266	950	40	10
Microtube	140	175	200	800	700	30	10
Raingun	152	200	200	760	760	20	10
Subsurface drip	150	120	200	1250	750	52	10
Drip- fertigation	212	150	180	1413	1170	40	20

Source: Anon. (2004-05, 2005-06, 2006-07, 2007-08)

Epilogue

The cultivated land per capita is becoming limited day by day, soils subject to various kinds of degradation, scarcer safe water availability for irrigation, low and imbalanced use of plant nutrients, over-mining of plant nutrients from the soil for crop production, low use efficiency of nutrients, especially the nitrogen having global implications including the global warming, emerging micro and secondary nutrient deficiencies, contamination of soils with heavy metals, low water use efficiency, ever increasing demand for food with rising population, rising cost of inputs, etc. making it imperative to lay emphasis on the efficient use of natural resources with least adverse impact on soil and environmental health. There is no way out than to adopt good soil management practices like inclusion of leguminous crops in the cropping system, balanced fertilization, integrated nutrient management involving organic manures, recycling of available crop residues, green manuring/green leaf manure addition, bio-fertilizers, etc. along with chemical fertilizers to provide not only good nutrition to crops for meeting out the requirement of major and micro-nutrients but also to restore and maintain good soil health for higher and sustainable crop production with least adverse impact on the environment. Conservation agriculture involving conservation tillage with surface layer of crop residues is a step towards sustainable agriculture that not only conserves water and favourably moderates thermal regime, physical, chemical and biological soil environment, but also helps in realizing higher nutrient, water and energy input use efficiency.

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Article-2

Need for a paradigm shift in fertilizer management in India[1]

It has been estimated that to feed this massive population in 2050, a four-fold increase in land productivity, a three-fold increase in water productivity, doubling of energy use efficiency, and a six-fold increase in labour productivity would be necessitated because there is no possibility of an increase in the net cultivated area which stands at 140$\pm$ 2 Mha. Add to it, are the continuously declining water availability and total factor productivity as well as degrading soil resources. In fact, highly productive agricultural land is fighting a losing battle with the likes of industry and urban development. "Evergreen Revolution", "Sustainability" have, therefore, become buzz words today. Intensification of agricultural activities in a sustainable manner with adoption of modern tools and eco-friendly green technologies (nature-based solutions) is the only option available if we have to achieve the UN prescribed Sustainable Development Goals (SDGs) by 2030.

It is a well-established fact that in addition to water, fertilizers played a key role in making India's Green Revolution a reality and is a vital element contributing towards enhancing the food production targets set by the Government to feed the 17.5% of the global population on 2.4% of the world's land resources out of which 120.72 Mha suffers from degradation of different categories. India is second largest producer of nitrogenous and third largest producer of the phosphatic fertilizer in the world. It ranks as number two as far as consumption of the two fertilizer products are concerned. India imports all its potassic fertilizer requirements and is the world's fourth largest consumer. As a policy matter, fertilizers are highly subsidized and the magnitude of the subsidy is around Rs. 70,000 crores every year. It is generally said that the average fertilizer use in India is less than in the neighbouring countries e.g., China, Bangladesh, Pakistan. For example, in 2016, it was 153.1 $kgha^{-1}$ in India, 268.2 $kgha^{-1}$ in Bangladesh, 354.1 $kgha^{-1}$ in China and 158.3 $kgha^{-1}$ in Pakistan, while it was 101.5 $kgha^{-1}$ in Sri Lanka when fertilizer consumption is expressed as fertilizer consumption per hectare of arable land and land under permanent crops (FAI, 2018).

Impact on the environment and inefficiencies of fertilizer application in soil

In India, fertilizer application method largely adopted is broadcasting, which is the most inefficient way of applying fertilizers to a crop. Table 1 shows the efficiency of fertilizer use. Since significant amount of the fertilizer applied is going into the environment, contributing to contamination of ground water and GHG emission. Recent estimates show that during the period from 1970 to 2010, nitrous oxide emission has increased by 380% in India. It is fairly well known that Nitrous oxide gas (N_2O) has a global warming potential which is approximately 300 times that of CO_2 and a residence time of almost 120 years. It is solely caused by the application of fertilizers. Nitrate contamination of ground water is also a consequence of excessive use of chemical fertilizers. Phosphorus, which is fixed in soil, finds its way to water bodies along with run-off water and pollutes them affecting water quality and aquatic life.

It is thus obvious from Table 1, there is a huge scope for improving their use efficiencies. In addition to the environmental impacts, another very urgent compulsion for improving the efficient use of fertilizers is the huge amount that the exchequer has to shell out on subsidy to this sector. It was more than Rs. 70,000/- crores for the year 2018-19.

Table 1. Nutrient use efficiencies in soil application

Nutrient	Efficiency, %	Causes of low efficiency
Nitrogen	30-50	Immobilization, Volatilization, Denitrification, Leaching
Phosphorus	15-20	Fixation in soils Al – P, Fe – P, Ca – P
Potassium	70-80	Fixation in clay - lattices
Sulphur	8-10	Immobilization, Leaching with water
Micronutrients (Zn, Fe, Cu, Mn, B,etc.)	<5	Fixation in soils

Source: Nagar (2018)

Future suggestions

Fertigation

One typical example is the use of water-soluble fertilizers in drip irrigation systems i.e., fertigation. This also fits in with the push that the Government of India is giving to pressurized irrigation systems through "per drop more crop" objective of the Prime Minister Krishi Sinchai Yojna (PMKSY). The potential area that can be brought under drip irrigation has been estimated to be around 27.5 Mha while the current area is 6 Mha only. Table 2 indicates the efficiencies which can be attained through drip fertigation.

[1]First Prof. N.P.Datta Memorial Lecture of Society for Fertilizers and Environment delivered on 27 March, 2019 at BCKV, Kalyani, West Bengal

Table2.Fertilizer use efficiency of different application techniques

Nutrient	Fertilizer Use Efficiency (%)		
	Soil Application	Drip without Fertigation	Drip + Fertigation
Nitrogen	30-50	65	95
Phosphorous	20	30	45
Potassium	50	60	80

Source: agritech.tnau.ac.in/agriculture/agri_nutrientmgt_fertigation.html

Neem-coated urea

Sale of only coated urea was the first step taken by the government in this direction followed by reducing the quantity of fertilizer sold in each bag from 50 kg to 45 kg as farmers traditionally think in terms of bags of urea applied; and it has started paying dividends by increasing the efficiency and reducing the consumption.

Foliar spray

The effectiveness of foliar spray as an efficient way of applying nutrients is an established fact particularly of micronutrients. If timed to match the plants physiological requirement, it would enhance not only the application efficiency significantly but also the productivity and quality of the produce. The potential of foliar spray to provide the much-needed nutrients to the crops under rainfed conditions is yet to be fully exploited.

Fertilizer placement

Efficiency of subsurface placement of fertilizers, like band placement, was scientifically established quite some time back but had no takers. Presently, the machinery used for seeding in Conservation Agriculture have this provision and are gaining popularity in Northern India. In Bangladesh, deep placement of urea has made a huge impact. Urea Deep Placement (UDP) – a simple yet innovative technology – involves the placement of 1-3 g of urea supergranules or briquettes at 7-10 cm soil depth shortly after the paddy is transplanted. UDP increases nitrogen use efficiency because most of the urea nitrogen stays in the soil, close to the plant roots where it is absorbed more effectively. The benefits of the technology are significant – a 20 percent increase in crop yields and a 40 percent decrease in nitrogen losses. This technique can be suitably modified for other situations.

Land configuration

It would be worthwhile to mention that increase in water use efficiency invariably enhances nutrient use efficiency. Laser land levelling not only saves water but also increases nutrient use efficiency (Table 3). Similarly, Raised Bed system of crop establishment is also effective in saving water and improving nutrient use efficiency in addition to helping the crop to tolerate both water stress and waterlogging.

Table 3. Agronomic efficiency (kg kg^{-1}) of N (AE-N), P (AE-P) and K (AE-K) under different land levelling systems in rice

Treatment	AE-N		AE-P		AE-K	
	2003	2004	2003	2004	2003	2004
LL+NPK	18.75	20.00	86.54	92.31	56.25	60.00
TL+NPK*	7.67	9.17	35.38	42.31	23.00	27.50
LL-Laser levelling; TL-Traditional levelling. N @ 120 kg, P @ 26 kg and K @ 40 kg ha^{-1}						

Source: Jat *et al*., 2004

Site Specific Nutrient Management (SSNM)

More than 85% of the farmers in India belong to small and marginal category with farm holdings less than 2 ha. It would be a herculean task to go in for state-of-art precision farming in one go. It is recommended to go in for a balanced fertilizer based on the soil test report (Soil Health Card). Fig.1 shows the advantage of SSNM on the yields of rice-wheat cropping system compared to the farmers' practice. The yield advantage could vary from 2 to 5 t ha^{-1} except for Ludhiana where yield benefit is not so high. Implementation of SSNM is easy with the information being generated on geo-referenced soil fertility status through the National Soil Health Mission and availability of mobile-based applications (Singh, 2017).

Customized Fertilizers

Since soils vary from location to location in terms of their fertility status as well as individual farmers' management level, customized fertilizer application can provide larger economic returns with negligible higher investment. Fig. 2 illustrates the enhancement in Partial Factor Productivity (PFP) as well as grain yield in rice crop. Considering the vast variability and diversity of the crops grown by farmers in India, making customized fertilizer available at a local level is a formidable task but its potential is immense.

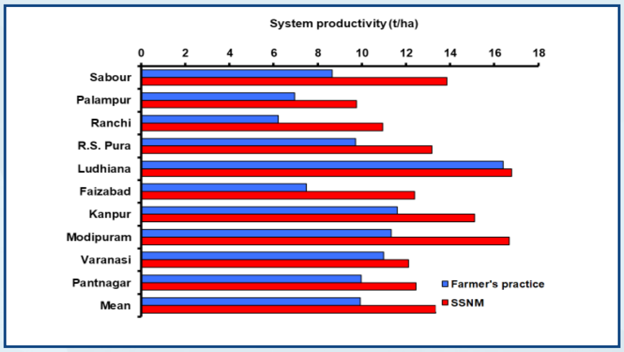

Fig. 1. Performance of site-specific nutrient management as compared to farmer's fertilizer practice under rice-wheat cropping system
Source: Singh, 2017

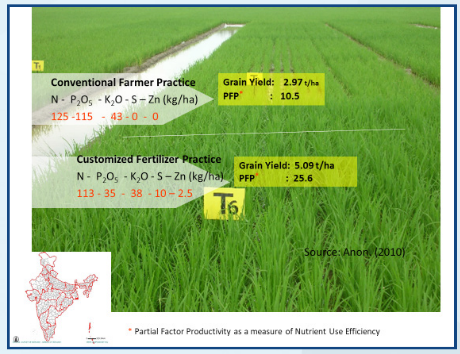

Fig. 2. Customized plant nutrition & improved nutrient use efficiency

Nanotechnology-based fertilizers

Nanotechnology-based applications in agriculture have a very bright future and the fertilizer sector is no exception. It has a huge potential to transform agricultural production by allowing better scientific management. Some advantages related to transformed formulation of conventional fertilizers using nanotechnology are given in Table 4 (Cui *et al.,* 2010).

However, it is essential to carry out environmental and human-related risks associated with use of nano-materials before recommending large scale use of such products.

NAAS (2019) organized a Brain Storming Session (BSS) on 'Novel Fertilizers' and the outcome of the meeting very categorically brought out the fact that the nutrient-based subsidy should have been applicable to all fertilizer products without exception to avoid imbalanced fertilizer application. Direct Benefit Transfer (DBT) of the subsidy to the farmers would benefit them. The Fertilizer Control Order may be replaced by a suitable act to create an environment conducive for introduction of new products. State-of-art Fertilizer R & D Centres should be set up in the country along with Fertilizer Quality Control laboratories. There is a need for degree courses in Fertilizer Chemistry and Technology as well as develop courses related to Fertilizer Engineering in Chemical Engineering degree course. This may kick-start the fertilizer sector to come up with some new products.

Table 4. Potential of nanotechnology-based fertilizers

Desirable properties	Examples of nanofertilizer-enabled technologies
Controlled release formulation	So-called smart fertilizers might become a reality through transformed formulation of conventional products using nanotechnology. The nanostructured formulation may permit fertilizer to intelligently control the release rate of nutrients to match the uptake pattern of crop.
Solubility and dispersion for mineral micronutrients	Nanosized formulation of mineral micronutrients may improve solubility and dispersion of insoluble nutrients in soil, reduce soil absorption and fixation, and increase the bio-availability.
Nutrient uptake efficiency	Nanostructured formulation might increase fertilizer efficiency and uptake ratio of the soil nutrients in crop production, and save fertilizer resource.
Controlled release modes	Both release rate and release pattern of nutrients for water-soluble fertilizers might be precisely controlled through encapsulation in envelope forms of semi-permeable membranes coated by resin-polymer, waxes and sulphur.
Effective duration of nutrient release	Nanostructured formulation can extend effective duration of nutrient supply of fertilizers into soil.
Loss rate of fertilizer nutrients	Nanostructured formulation can reduce loss rate of fertilizer nutrients into soil by leaching and/or leaking.

Source: Cui *et al.,* 2010

Epilogue

Considering the massive cost that the government spends on the fertilizer production and utilization, plus the negative fall-outs of excessive and imbalanced use on soil health, environment, water quality, and human health, it is the most appropriate time to concentrate on this critical and inevitable input in terms of its application techniques, production of novel (smart) fertilizers, and use of remote-based sensor technology so that Indian agriculture ultimately shifts towards precision farming without further delay. It should be complemented by a relentless pursuit of identifying and incorporating genes that can improve nutrient use efficiency so that the farmer ultimately benefits by spending less for more.

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Article-3

Impact of rice straw burning on the environment and alternative managements to mitigate the damage

Rice straw burning is still a prevailing practice in South-Asian countries including India. Lack of field preparation – time for next season's crop, high cost of carrying of straw from field to outside, spreading of chopped straw on the field after combined-harvester use, weeds removal problem, and, as generally believed, less diseases and pests infestation in succeeding crops, are the major reasons mentioned for straw burning on the field (Gadde *et al*., 2009).The unrestricted burning of rice straw leads to emissions of miscellaneous pollutants like carbon monoxide (CO), carbon dioxide (CO_2), sulphur dioxide (SO_2), oxides of nitrogen (NOx), ammonia (NH_3), non-methane volatile organic compounds (NMVOCs), methane (CH_4), particulate matter (PM_{10}, $PM_{2.5}$), organic carbon (OC), elemental carbon, etc. (Oanh *et al*., 2018). Emissions and dispersion of pollutants differ according to seasons, climatic condition and type of residue. Moreover, the declining quality of atmosphere due to straw burning and its dissemination in surrounding areas are of great concern due to its harmful effects on the environment and human health (Ravindra *et al*., 2016). Several studies show that rice straw burning is one of the important factors for loss of major nutrients in soil, like nitrogen (100% loss), phosphorous (25% loss), potassium (20% loss) and sulphur (5–60% loss) (Dobbermann and Fairhurst, 2002).

Environmental consequences of rice straw burning

Depletion of air quality due to trace gas and aerosol emission

One tonne of rice straw releases 3 kg particulate matter, 60 kg CO, 1460 kg CO_2, 199 kg ash and 2 kg of SO_2, on burning. It is also responsible for emission of large quantity of particulates that are made up of heterogeneous organic and inorganic substances. It is estimated that 70, 7 and 0.7% of carbon present in rice straw are liberated as CO_2, CO and CH_4, respectively, while, 2.1% of nitrogen in straw is released as N_2O as a result of burning (Hays *et al*., 2005). Comparative assessment of current and future emissions of miscellaneous pollutants from burning of rice straw in India is given in Fig 1.

Deterioration in soil health and fertility

Repetitive burning in the agricultural field permanently reduces microbial population. Continuous burning reduces total nitrogen and carbon and potentially mineralized nitrogen up to 15 cm soil layer. Burning also kills beneficial soil microflora and fauna (Ahmed and Ahmad, 2013). Soil temperature could rise up to 33.8-42.2°C at surface soil due to burning of straw. As an effect of rise in temperature about 23–73% of nitrogen is lost and the microbial population is reduced sharply at top soil (Kumar *et al*.,2015).

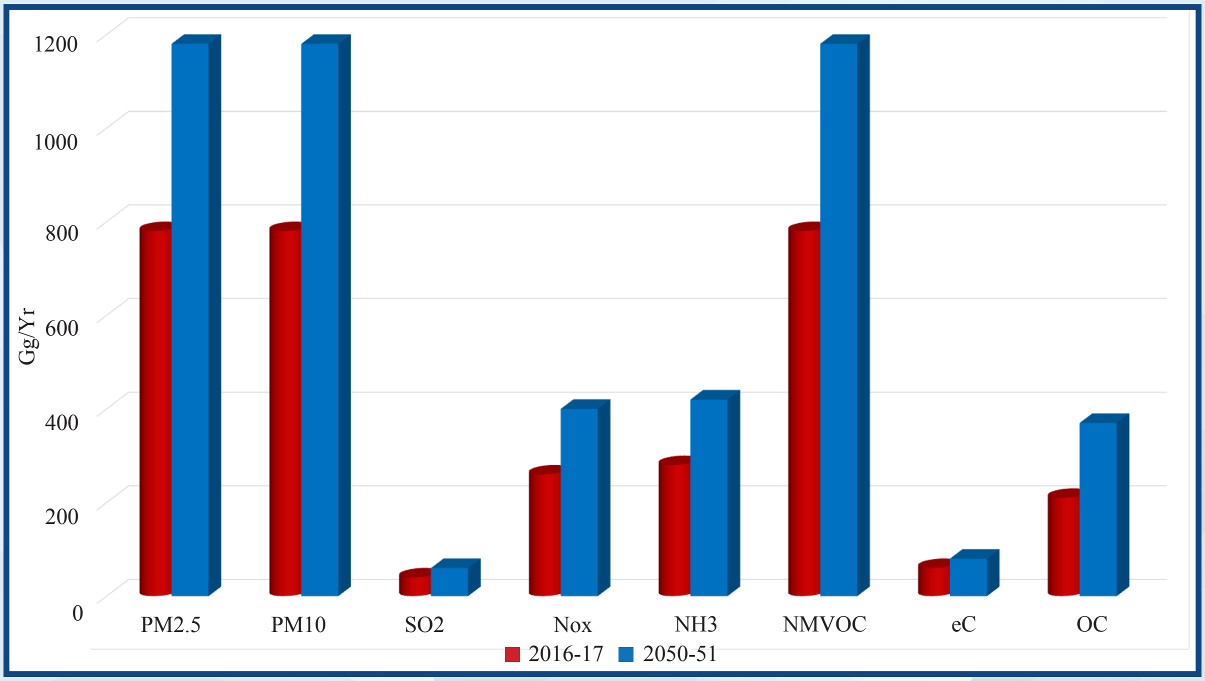

Fig. 1. Comparative assessment of current and future emissions of miscellaneous pollutants from rice straw burning in India [particulate matter (PM_{10}, $PM_{2.5}$), sulphur dioxide (SO_2), oxides of nitrogen (NOx), ammonia (NH_3), Non-methane volatile organic compounds (NMVOCs), elemental carbon (eC), organic carbon (OC)]
Source: Ravindra *et al*., 2018

Technological alternatives of rice straw management: possibility and challenges

There are different rice straw management options which have the potential to transform rice straw into other assets (useful bioresources). These alternatives would not only help to reduce air pollution, GHG emissions, limit the extent of climate change, but also would help to generate economic gains to farmers.

Management options are broadly classified into 'on-farm' and 'off-farm'. 'On-farm' managements include straw incorporation, retention, mulching, etc. and 'off-farm' options provide energy conversion through biochar, biofuel, paper pulp production, mushroom cultivation, etc.(Bhattacharyya and Barman, 2018). A comparative assessment of rice straw management options and GHG emission is presented in Table 1.

Rice straw retention and incorporation

The retention followed by incorporation of rice straw in agricultural soil is a reasonably eco-friendly alternative to straw burning, as these management practices enhance the soil carbon and nutrient status gradually. However, this practice may increase weed infestation, soil compactness, and GHG emissions. The incorporation of straw in paddy facilitates methane emission by providing labile carbon substrates to methanogens (Romasanta *et al*., 2017). The main cause of decrease in N_2O emissions immediately after straw application is due to the reduction of N_2O to N_2.

The GHG emission due to incorporation is however much less as compared to burning for the same amount of rice straw. Moreover, organic matter content and the organic carbon content in soil increases by incorporation of rice straw. Soil organic carbon acts as an excellent binding agent and plays a crucial role to form a stable soil aggregates and improve soil structures.

Table 1. Comparative assessment of GHGs emission as affected by different rice straw management options

Management practices of rice straw	Reduction in GHGs emission compared to burning (%)			Justification	Reference
	CH_4	N_2O	Global warming potential (GWP)		
Straw retention	-47.7	17.4	-	Favourable for CH_4 formation as provided more labile carbon into reduced soil. Reduction of N_2O to N_2 causes less nitrous oxide emission	Romasanta *et al.*,2017
Straw incorporation	-12.5	21.74	-	Provides labile carbon to soil, favourable for CH_4 formation. Decrease in N_2O emissions due to higher mineral N immobilization, decreased soil Eh, and increased soil Fe^{2+}content	*Romasanta et al.,2017*
***In-situ* decomposition**	-19.3	57.8	-	The anaerobic decomposition of carbon provides substrates for methanogens, enhanced methane production	Romasanta *et al.*,2017
Biochar	75	-39.1	66.5	Reduced CH_4 emissions due to the stimulation of methanotrophic activity. Increased N_2O emissions due to the additional nitrogen input.	*Shen et al., 2014*
Substrate for mushroom production	37.25	47.7	7.3	Comparatively low emissions of CO, CH_4 and NMVOC from mushroom cultivation; reduces the air pollution.	Arai *et al.*, 2015

Biochar

Addition of biochar to the soil helps to hold the soil carbon for several years (Shen *et al*., 2014). Rice straw by the process of pyrolysis could be transformed to biochar which has the potential to reduce carbon footprints by 38-49% from rice production system. Hence, use of biochar is a sustainable alternative, which could help to mitigate climate change as it helps in carbon sequestration.

Straw decomposition

Composting is the decomposition of rice straw for recovery/enriching of nutrients and organic components. It is generally done in open natural condition or in an enclosed controlled chamber. The quality of compost depends on conditions during composting like, availability of oxygen, moisture content, pH, temperature, and the C:N ratio. Rice straw decomposes slowly and usually would take up to a 6-8 months to complete the process (provided moisture is available in tropical/ subtropical climate). Several simple and rapid composting techniques are developed to convert huge amount of rice straw into organically rich compost. The beneficial effect of compost is well known (increase crop yield by 4 to 9%) but the problem is associated with labour availability and prolonged time of composting (Pandey *et al*., 2014). Recently developed efficient microbial strain with suitable package of practice could decompose the rice straw both in *ex-situ* and *in-situ* conditions in less than 30-35 days.

Use of rice straw as substrate for mushroom production

Rice straw is an essential component used as a substrate for rice straw-mushroom culture. Use of rice straw for mushroom production is a win-win situation where, we can convert a waste (burned rice straw to ash) to an asset (substrate for a high-value mushroom). Apart from this, mushroom cultivation provides good employment opportunity to rural youth and give economic yield to farming community. Moreover, as compared to burning the same amount of rice straw, GHG emissions due to mushroom production is much less (straw burning, 1469-2098 g CO_2eq. kg dry-straw^{-1}; straw-mushroom cultivation, 1362–1461 g CO_2eq. kg dry-straw^{-1} (Arai *et al*., 2015). Mushroom beds were conventionally air-dried for several weeks and piled up before the cultivation, that was the main cause of less emission (Arai *et al*., 2015).

Bioethanol and Bioenergy

Rice straw having lingo-cellulosic biomass is considered fruitful for the production of energy and generation of ethanol (Bhattacharyya and Barman, 2018). About 205 billion liter bioethanol per year could be produced from rice straw in the world, which may be 5% of total of ethanol required.

Biogas production from rice straw in combination with other organic products is an age-old technology in the rice-growing areas. It has several benefits, including supplying of plant nutrients to the soil. In addition, biogas slurry can be used as soil amendment to mitigate GHGs emission as compared to the addition of raw organic manure. Escalating fuel prices and climate change/environmental issues may re-stimulate the future of biogas from rice straw (Bhattacharyya and Barman, 2018).

Conclusion

It is concluded that, rice straws are of high economic value for biogas, manure, and biochar production. It also has been used as livestock feed and raw material for paper industry. Farmers are aware of the deleterious effects of rice straw burning at the field condition but the main constraint is non-availability of economically viable and acceptable machineries as well as lack of different alternatives for disposal of huge amount of rice straw. However, rice straw can be best utilized for production of energy and has the potential to meet 10% of current energy demand of India.

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Honours and Awards

Prof. Biswapati Mandal, Professor, Directorate of Research, Bidhan Chandra Krishi Viswavidyalaya, Kalyani and Secretary of SFE received the prestigious **N S Randhawa Memorial Award 2019** during 14th Agricultural Science Congress at NASC Complex, New Delhi for his remarkable contributions in the field of Soil Science, especially, soil quality and soil organic carbon management.

Prof. Mandal also received the Platinum Jubilee Commemoration Award of Indian Society of Soil Science for his outstanding contributions related to the objectives of Indian Society of Soil Science during Nov., 2018.

Dr. Feroze Hasan Rahman, Pr. Scientist, ICAR-ATARI, Kolkata and Jt. Secretary of SFE received **Society for Extension Education FELLOW 2018 AWARD** during 9th National Extension Education Congress at Central Agricultural University – College of Agriculture and Post Harvest Engineering Campus for his outstanding contribution in the field of extension education.

Dr. Rahman has also been nominated by Hon'ble Director General, ICAR as **MEMBER SECRETEARY** to the Quinquennial Review Team to review the performances of the KVKs of Zone IV and V during last eight years from 2011-12 to 2018-19.

Dr. Dibyendu Sarkar, Asst. Professor, BCKV and Treasurer of SFE received the **Lal Bahadur Shastri Outstanding Young Scientist Award 2018** in Natural Resource Management & Agricultural Engineering. In his 16 years of research career, Dr. Dibyendu Sarkar worked on different aspects of soil fertility, nutrient management and C-sequestration for attaining sustainability of agricultural production systems and livelihood and nutritional security of the farming community. Dr. Sarkar also established the mechanistic pathways for C-sequestration and its stabilisation for a net C enrichment in soils under different land uses for maintaining soil health and curbing global warming.

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