



SAARC TRAINING Manual

Integrated Nutrient Management for Improving Soil Health and Crop Productivity



Editors

Pradip Dey
Sanjay Srivastava
N.K. Lenka
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A.K. Vishwakarma
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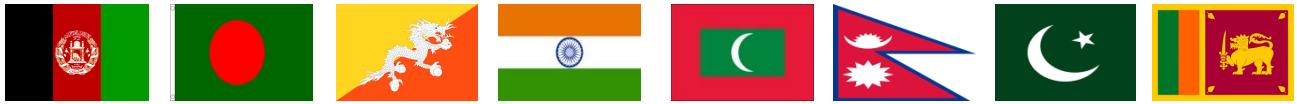
SAARC Agriculture Centre (SAC)
South Asian Association for Regional Cooperation, Dhaka, Bangladesh



International Rice Research Institute



Organised by
ICAR-Indian Institute of Soil Science, Bhopal, India



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Integrated Nutrient Management for Improving Soil Health and Crop Productivity

SAARC Regional Training Programme on *Integrated Nutrient Management for Improving Soil Health and Crop Productivity* during 5-10, September, 2018 at ICAR-IISS, Bhopal - 462038, Madhya Pradesh, India

Editor: Pradip Dey, Sanjay Srivastava, N.K. Lenka, Shinogi K.C., A.K. Vishwakarma and Ashok K. Patra

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ICAR-Indian Institute of Soil Science, Bhopal, India



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MESSAGE

I am happy to know that ICAR-Indian Institute of Soil Science, Bhopal is organizing a regional training course on *Integrated Nutrient Management for Improving Soil Health and Crop Productivity*, sponsored by SAARC Agriculture Centre (SAC), Bangladesh and International Rice Research Institute (IRRI), Philippines from 5-10 September, 2018.

South Asia is predominantly agrarian based region with more than 50% of the population depending on agriculture for their livelihood. Use of high analysis fertilizer although ensured the high production, it has also resulted in acceleration of mining of native sources of nutrient. This has led to appearance of hidden hunger of several other essential nutrients and sustainability of our agriculture has become vulnerable. Under this scenario, Integrated Plant Nutrient Management System (IPNS) which has evolved over generations across the region can be a useful holistic approach to management of plant nutrients in different land use systems. The IPNS incorporates many technologies including soil conservation, nitrogen fixation, and organic and inorganic fertilizer application. Further, by enhancing crop growth, inorganic fertilizer application has the added benefit of increasing the biomass of crop residues, which can in turn be reincorporated into the soil as a green manure to improve the structure and organic matter content of the soil.

I am sure that the participants from SAARC countries would be exposed to many conventional and new approaches employed for the pragmatic implementation of integrated plant nutrient management system for enhancing crop yield and sustaining soil health. Further, this training would also provide a common platform to the researchers from fellow SAARC countries to discuss prevailing practices related challenges in plant nutrition and also developing region specific strategies for improving production.

I wish the training a great success.

(T. Mohapatra)

Dated the 20th August, 2018
New Delhi



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MESSAGE

During the Green Revolution era, from 1965 to 1995, fertilizers have been responsible for 55% of the yield increase in developing countries (FAO, 1995). It is also estimated that about two-thirds of the needed increase in crop production in developing countries will have to come from yield increases from lands already under cultivation. Recent FAO Study is that between 2015/2030 indicates that the fertilizer consumption in the world is expected to increase from 134 million tons in 1995/97 to 182 million tons in 2030, at an annual growth rate of 0.9%. Wheat, maize and rice will continue to be the dominant fertilizer consuming crops, with maize emerging to be the foremost user in 2030, closely followed by wheat and rice. Since these three crops are the predominant crops in Asia, the Asian trend of fertilizer use will determine the trend of use in the developing countries as a whole. Asia is projected to consume 86 million tons of fertilizer nutrients by 2030, accounting for 47% of the world's and 77% of the developing countries' fertilizer consumption.

To address this issue Integrated Plant Nutrient Management System (IPNS) which has evolved over generations across the region can be a useful holistic approach to management of plant nutrient management in different land use systems. Although the increasing competition of population growth, farming and urbanization for use of agricultural land creates the condition for a paradigm shift to the conscious campaign to develop and promote the awareness and capacity of Integrated Plant Nutrient Management System as a national, regional and global strategy. Population growth, urbanization and industrialization will compete for more lands from the agricultural lands. Hence, the projected yield increases have to be met with greater mobilization and efficient use of nutrients, of both inorganic and organic sources. Thus the development of Integrated Plant Nutrient System (IPNS) to suit different farming systems is a major challenge for all stakeholders in agriculture to ensure sustainable food security. IPNS as a concept and farm management strategy embraces and transcends from single season crop fertilization efforts to planning and management of plant nutrients in crop rotations and farming systems on a long-term basis for enhanced productivity, profitability and sustainability.

I am glad that these issues are receiving due consideration in the SAARC Regional Training. I am confident, the participants from SAARC Member States will get enough exposure through this training program to address the issue plant nutrition management and strengthening national capacity to implement Best Management Practices and take advantage of the innovations in IPNS.

I wish the SAARC Regional Training Program on “**Integrated Nutrient Management for Improving Soil Health and Crop Productivity**” all success.

Dated the 9th August, 2018
Place: Dhaka, Bangladesh


(S. M. Bokhtiar)

PREFACE

South Asia is predominantly agrarian based region with more than 50% of the population depending on agriculture for their livelihood. Agricultural impacts of climate change will manifest in terms of changes in land and water resources, insect pest populations, diseases, etc. which ultimately translate into a change in productivity and profitability of agriculture. With crop intensification and decline in per capita land availability, maintaining soil health under intensive cropping system is a big challenge. Continuous use of chemical fertilizer in indiscriminate manner without assessing soil also had adverse effect on productivity and environment. Use of high analysis fertilizer although ensured the high production, it has also resulted in acceleration of mining of native sources of nutrient. This has led to appearance of hidden hunger of several other essential nutrients and sustainability of our agriculture has become vulnerable.

Under this scenario, Integrated Plant Nutrient Management System (IPNS) which has evolved over generations across the region can be a useful holistic approach to management of plant nutrient management in different land use systems. Although the increasing competition of population growth, farming and urbanization for use of agricultural land creates the condition for a paradigm shift to the conscious campaign to develop and promote the awareness and capacity of Integrated Plant Nutrient Management System as a national, regional and global strategy. Thus the successful IPNS system can combat the loss of farm productivity is a profitable investment for sustainable rural livelihood, food security and the environment. Hence, the projected yield increases have to be met with greater mobilization and efficient use of nutrients, of both inorganic and organic sources. Thus the development of Integrated Plant Nutrient System (IPNS) to suit different land use systems is a major challenge for all stakeholders in agriculture to ensure sustainable food security. IPNS incorporates many technologies including soil conservation, nitrogen fixation, and organic and inorganic fertilizer application. Further, by enhancing crop growth, inorganic fertilizer application has the added benefit of increasing the biomass of crop residues, which can in turn be reincorporated into the soil as a green manure to improve the structure and organic matter content of the soil.

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Research and development initiatives for managing soil health

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A lot of basic, strategic and applied research work has been carried out in different agro-ecological regions during the last two and half decades leading to increased understanding of soil health and development of viable technology packages based on sound soil and nutrient management strategies. Agro-ecological region and sub-region maps generated in India have globally received wide appreciations. Degraded and wasteland estimates have been reconciled. Integrated nutrient management practices have been developed for different crops on varying soil types. Integrated plant nutrient supply systems and site-specific nutrient supply systems have shown a new way forward for restoring soil health and quality. Adoptable site-specific technologies for enhancing the use efficiency of major, secondary and micronutrients have been developed. Developments in the field of new innovative fertilizer materials, biofertilizers and composting techniques are the important breakthroughs because of which the country has saved huge foreign exchange.

Soil health and quality remain a matter of great concern for the Government of India. In the last 25 years government made huge investment in arresting soil degradation and decline in fertility of the soils. For this purpose several developmental schemes have been implemented. Integrated Watershed Management Programme (IWMP) has benefitted thousands of the field functionaries and farmers directly through skill development and capacity building. National Mission for Sustainable Agriculture (NMSA), a recent initiative, is being successfully run across length and breadth of the country. Soil health management, a sub-scheme of NMSA, is promoting soil test-based balanced and integrated nutrient management in the country. Central Government, State Governments and NABARD are providing support in various forms to strengthen soil health programmes in different names. More recently (in 2015), a National Mission on Soil Health Card has been launched to provide soil test-based fertilizer recommendations to all the farmers in the country.

Assessment of Research Initiatives The atmospheric concentration of carbon dioxide (CO_2) has increased globally by 40% over that in the pre-industrial era. Efforts are being made globally to reduce or stabilize the atmospheric CO_2 concentration. To achieve this goal, a number of strategies advocated, *inter alia* include biotic carbon (C) sequestration in soil and vegetation. The rate and magnitude of soil C sequestration differs with soil quality, climatic conditions, land-use and management. Despite unfavourable climatic conditions, there are considerable opportunities for C sequestration in Indian soils. Adoption of the best management practices (BMPs) such as intensive agriculture, growing of high biomass producing crops, residue recycling, application of organic amendments, adoption of agroforestry systems, diversified crop rotations, and conservation agriculture can play an important role in enhancing soil C sequestration. Balanced application of fertilizers and integrated nutrient management are other options that have capacity to enhance soil C sequestration by 20-600 and 100-1200 $\text{kg C ha}^{-1} \text{ yr}^{-1}$, respectively. Agroforestry systems though exhibit higher rate of soil C rehabilitation, but are characterized mainly by labile forms of SOC, thereby suggesting that the accumulated C may be lost following the land-use change. Climate change is likely to influence the rates of accumulation and decomposition of SOM, especially in regions with low temperature. Per degree warming may increase SOC loss by 8-9% in the regions with temperatures of 10-15°C compared to only about 2% in a soil at 35°C. However, to predict the net effect of climate change on SOC strong knowledge on the relative temperature sensitivity of organic matter decomposition and primary productivity is required.

Some of the strategic approaches for restoring, improving and maintaining soil quality and ensuring agricultural sustainability developed by the researches in the country include i) controlling soil erosion, ii) promotion of agricultural management practices which enhance SOM, iii) development and promotion of other bioresources for enhancing microbial diversity, vi) revamping and reorientation of soil testing programmes and ensuring site-specific nutrient management, v) promotion of balanced multi-nutrient fertilizers, vi) increasing input (nutrients and water) use efficiency through precision farming techniques, vii) amendment of problematic soils, viii) conservation tillage with promotion of land cover management, ix) restriction on mining activities and misuse of top soil for other purposes such as bricks making, x) launching of mass awareness programmes among farmers about importance of land and soil resource and its care, through all possible communication means, and xi) creation of national apex statutory bodies to coordinate land care and soil quality improvement programme in the country. Additionally, induction of conservation agriculture is a necessity of Indian agriculture. Its application and adoption must be promoted in right earnest. Assessment of Developmental Initiatives Government of India is promoting the soil test-based balanced and INM encompassing chemical fertilizers, biofertilizers and locally available organic manures like farmyard manure (FYM), compost, vermicompost and green manures to maintain soil health and crop productivity. In 2012-13, the annual soil analyzing capacity in the country was 12.83 million soil samples. The soil testing facility is provided to the farmers free of cost or with some nominal fee by the State Governments. Till March 2013, about 56.93 million soil health cards were issued to the farmers. Under the National Project for Management of Soil Health and Fertility launched during 2008-09, there is a provision to set up new static soil testing laboratories (STLs) and new mobile soil testing laboratories besides strengthening of existing laboratories to enable them to undertake micronutrient testing.

Apart from the above, other components under this scheme are training and demonstration on balanced use of fertilizers, promotion of organic manures, soil amendments and micronutrients and setting up/strengthening of Fertilizer Quality Control Laboratories. In order to prevent soil erosion and land degradation, Government of India, Ministry of Agriculture is implementing various watershed programmes, namely; National Watershed Development Project for Rainfed Areas (NWDPR), Soil Conservation in the Catchments of River Valley Project and Flood Prone River (RVP&FPR), and Reclamation and Development of Alkali and Acid Soils (RADAS) across the country. Ministry of Rural Development is implementing the IWMP for the purpose. About 57.61 Mha area has been developed under various watershed development programmes of the Ministry of Agriculture and Ministry of Rural Development since inception up to 2011-12. Besides, 1.5 Mha of sodic land has been reclaimed using gypsum technology and 0.5 Mha saline land area has been reclaimed using sub-surface drainage technology across the country. The Government implemented a centrally sponsored scheme 'RADAS' through Macro Management of Agriculture (MMA) Scheme in seven states. Since inception up to March, 2013 almost 9.0 lakh ha has been developed. This programme was discontinued from April, 2013 due to closure of MMA. National Mission for Sustainable Agriculture (NMSA) was launched in April, 2014 with a component of Reclamation of Problem soils (viz., saline, alkali and acid soils). The cost norm under this programme for reclamation of problematic soils is 50% of cost to the limit of Rs. 25,000 ha⁻¹ and Rs 50,000 per beneficiary for salt-affected soils.

Planning Commission constituted a Working Group of Sub-Committee of the National Development Council (NDC) on Agriculture and Related Issues on Dryland/ Rainfed Farming Systems including Regeneration of Degraded Waste Land, Watershed Development Programme to suggest various steps to be taken for effective utilization of natural resources especially in rainfed areas including measures/programmes for land resource development in the XI Five Year Plan and requirement of funds and also the area to be covered under the programmes of various Ministries/Departments as well as the State Governments. The committee in its report recommended the formulation of a Centrally Sponsored Scheme for Reclamation of Problem soils during XI Plan with enhanced unit costs and Government of India assistance. Furthermore, as recommended by the Committee Constituted by National Development Council (NDC) and also with a view of reclamation and development of problem soils (alkali, saline and acid) to meet the demands of food grain of ever-increasing population, prevention and control of waterlogging, salinization and alkalinity, a centrally sponsored scheme for reclamation of problem soils has been proposed as a sub-scheme of *Rashtriya Krishi Vikas Yojana* (RKVY)/NMSA during XII Plan.

After having implemented this scheme on pilot basis in selected major states, it may be taken up as standalone Centrally Sponsored Scheme after XII Plan.

Major Constraints and Challenges of Soil Health Programmes

Currently, a number of states are facing a shortage of requisite technical personnel for manning the soil testing laboratories. A drive for recruitment of qualified personnel must be accorded the topmost priority for successful management of soil testing programme in the states. Training of existing manpower is another area requiring immediate attention. Some states are hiring contractual manpower or are operationalizing soil testing facilities in public private partnership (PPP) mode to overcome the inadequacy of manpower. Even in such cases, adequate training remains an area of concern.

Major Policy Issues Related to Soil Health Management

Contemporary policy issues have been discussed by various authors in the recent past. Some of the most relevant issues discussed in a recent status paper (NAAS 2016) are reiterated here. There are several natural soil degradation processes like desertification, erosion, salinization, etc. However, anthropogenic activities have not only accelerated the pace of these degrading processes, but also created new types of threats on this precious soil resource.

Diversion of Agricultural Lands for Other Competitive Uses

As population expands and urbanization spreads, per capita area available for cultivation becomes less and less available with consequent reduction in agricultural production. This happens in two ways viz., (a) removal of top soil for brick-making and for other construction activities, and (b) sealing of soil for housing, road or other infrastructure. About 7% of the geographical area, for which land-use statistics is available, is used for non-agricultural purposes; this area is estimated to be increasing at the rate of 0.3 Mha yr^{-1} .

Soil Pollution

Chemical pollutants enter into the soil body through various processes. For example, soil becomes sink for i) pollutants originating from emissions from industries, power plants, vehicles, radioactive and toxic chemical fallouts during disasters; ii) gas-dust releases into the atmosphere under high temperature technological processes (e.g. power plants, metal smelting, the burning of raw materials for cement, etc.); and iii) waste incineration and fuel combustion. In India, about 100 Mt of pollutants are being added to the atmosphere annually through burning of fossil fuel and industrial emissions causing considerable air pollution. Coal combustion in thermal power plants releases 100-110 t Hg yr^{-1} , which finally gets precipitated on soil body. Polluted surface and ground-waters upon their use for irrigation add several harmful chemicals into the soil. Significant proportion of more than 35 billion litres of urban wastewater and 25 billion litres of industrial wastewater carrying different pollutants released everyday upon its use for irrigation enters into agricultural land. Intake of potential carcinogenic and non-carcinogenic persistent organic pollutants (POP) like polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB) and other organic pollutants from contaminated soil may occur via ingestion, and inhalation or dermal (skin) exposure to contaminated soil/dust. Some of the pollutants are the constituents of extensively used agrochemicals like fertilizers (e.g. Cd through phosphatic fertilizer) and pesticides (organic pollutants) etc. These pollutants enter into the rhizosphere when their carriers are used for higher production and attractive economic returns.

A study at the IISS, Bhopal indicated high concentration of heavy metals (Cd, Cr, Cu, Pb, Ni and Zn) in composts generated in many cities of India from mixed municipal solid wastes. Repeated applications of these heavy-metal-rich composts on to agricultural lands may irreversibly pollute such soils.

Skewed N:P:K Ratio

Degradation of soil health has also been reported to be due to long-term imbalanced use of fertilizer nutrients. The N:P:K use ratio has gone skewed, more so in high urea consuming states, indicating urgent need for restoring the soil nutrient balance. Although overall nutrient use (N:P₂O₅:K₂O) of 4:2:1 is considered ideal for Indian soils, but the Indian Council of Agricultural Research always advocates soil-test based fertilizer prescriptions to avoid imbalanced use of nutrients in the soil. This imbalanced nutrient use widened the gap between removal of the nutrients by crops and their accretion through fertilizers. Long-term experiments in India have shown that the available P and K status in soils at all the centres exhibited a decline where only fertilizer N was applied.

Soil Erosion

Inappropriate soil management practices, such as tilling along the slope, lack of crop cover during heavy rainfall etc. are responsible for accelerated soil erosion with consequent loss of land productivity. Because of different processes like slaking and dispersion, mechanisms of soil structural collapse and degradation vary climatically; these also vary across the soil types. In addition to terrain deformation, erosion also takes away tonnes of nutrients to sea.

Soil Biodiversity

Maintenance of soil biodiversity is essential for food production, nutrient cycling, regulation of water flow, soil and sediment movement, and detoxification of xeno-biotics and other pollutants. Erosion, salinization, land sealing, and contamination with pesticides and heavy metal threaten soil biodiversity by destroying the habitat of the soil biota. Management practices that reduce organic matter in soils, or bypass biologically mediated nutrient cycling also tend to reduce the size and complexity of soil biotic communities.

Fertilizer Policy and Nutrient Management

There is a great concern about the adverse effects on soil health as well as productivity due to widening ratio of N:P:K use due to unsound policy decisions taken earlier, favouring prices of N and ignoring those of P and K. This has now been corrected to some extent. But without wholesome policies on pricing of fertilizers and of the agricultural commodities keeping long-term perspective in view, the impending disastrous effects of nutrient imbalances cannot be ruled out. Keeping in view the conservative population estimate of 1.4 billion needing minimum food-grains of 301 Mt by the year 2025, it will be necessary to use 30-35 Mt of NPK from fertilizer carriers and an additional 10 Mt from organic and biofertilizer sources. Thus, it will be essential for the country to raise the consumption and production of chemical and organic sources of plant nutrients by 2025 to meet these targets.

Soil test summaries show that about 49 and 9, and 45 and 39% of soils are low and medium in available P and K, respectively. There is also a growing evidence of increasing deficiency of P and K, aggravated by the disproportionate application of higher doses of N in relation to P and K. The recent aberration in prices of fertilizers has also changed the NPK ratio of fertilizer use from 5.9:2.4:1 in 1991-92 to 8.0:2.7:1.0 in 2013-14 indicating less use of P and K. This unhealthy trend needs to be reversed through development of appropriate strategies and policies to avert disastrous consequences.

There is a growing evidence of increasing responses to S in oilseed, pulse, legume and high yielding cereal crops. Presently, the gap between S removal and its addition to the crops is estimated to be about 0.5 Mt yr⁻¹ available S equivalent and it is likely to exceed 2 Mt yr⁻¹ by 2025. Strategies and policies need to be developed to reduce this gap and to encourage more use of S either through fertilizers containing S as component or by-products of fertilizers and sugar industry such as phosphogypsum and press mud, respectively. Pricing structure of S-containing fertilizers also merits reconsideration.

Changes in pricing of fertilizers, subsidies and decontrol of P and K fertilizers had caused a sudden and disastrous effect on the ratios of consumption of NPK. A long-term sound policy and mechanism

should be in place to encourage balanced and efficient fertilizer use. The question of subsidy on fertilizers should be viewed from a national perspective of food security, nutritional security and national independence. Fertilizer, being the key to national food security and agricultural development, must get the highest priority in any strategy of national planning.

Efficient Use of Fertilizer N

Nitrogen is necessary for all forms of life and is a crucial component for increasing production of food to feed the continuously increasing human population. However, barring di-nitrogen gas (N₂), which cannot be directly used in agriculture, all other reactive forms viz., urea, ammonia, nitrate and their derivatives, used to produce food can threaten the environment. Reactive N species (NO_x) are also formed from fossil fuel consumption by industries and vehicles, with attendant environmental implications. Major challenge facing Indian agriculture is to enhance the productivity of agricultural systems without adversely impacting environment and ecology. This is the basic dilemma for N management policies. The increase in food production has been a hallmark of the Green Revolution achieved through the use of improved crop varieties highly responsive to water and fertilizers, particularly nitrogenous fertilizers as the N-based fertilizers constituted a major fraction (70%) of the total fertilizer material. Increase in fertilizer N use in the last three to four decades has resulted in unprecedented increase in agricultural production in the north-western India, which made India a food-secure country. While interest in organic manures and biofertilizers has been growing steadily (and rightly so), these can't alone meet the total demand for fertilizers, at least in the near foreseeable future. The following points are of great importance in enhancing N use efficiency:

- Developing economically sound applicable policies and measures
- Providing incentives for improving N use efficiency through integrated nutrient management practices
- Integration of plant and animal production systems
- Conversion of agriculture from total reliance on synthetic reactive N fertilizers to significant input from biological N fertilizer (BNF)
- Development of modified N fertilizers - controlled release, urea-based fertilizers such as urea super granules (USG), neem-coated urea (NCU), etc. for lowland rice and other areas prone to reactive N leakages
- Novel molecular techniques to develop plants with higher N use efficiency • Accurate and site-specific test for estimating soil mineralizable N and developing site specific N management for different crops
- Development of N budgeting guidelines at field and farm levels and their further expansion to watershed scale requires urgent attention so that the effect of fertilizer N use in particular and overall N use in totality can be worked out for efficient management of N input in the agricultural systems.

Conclusions

Green Revolution technologies created revolutionary and significant growth in food production turning India from a country living on ship to mouth situation to the overflowing granaries during the last five decades. So extensive has been the over-exploitation of the soil resource that most of our soil-based production systems have started showing the signs of fatigue. The conservative estimates show that the demand for food grains would increase from 257 Mt in 2012-13 to 355 Mt in 2030. Contrary to increasing food demands, the factor productivity and rate of response of crops to applied fertilizers under intensive cropping systems have been showing progressive decline year-after-year. The current status of nutrient use efficiency is quite low due to deterioration in physical, chemical and biological health of soils. In India, soil health is synonymously used for soil fertility or nutrient status and soil physical and biological health is often ignored. Unfavourable soil physical conditions lead to poor crop yields and fertilizer use efficiency in

irrigated as well as rainfed agriculture. About 59% of Indian soils are low in available N, 36% medium and only 5% high. Similarly, soils of about 49, 45 and 6 per cent area are low, medium and high in available P, respectively and 9, 39 and 52% are low, medium and high in respect of available K, respectively. Assessment based on analysis of 127,812 soil samples showed that nearly 24.7, 43.4, 14.4, 6.7, 7.9 and 20.6% samples are deficient in S, Zn, Fe, Mn, Cu and B, respectively. With the exception of SOC, not much information is available in the country on other parameters of biological soil health. Though the biological indices are reliable as early warning signals of changes in soil health, no attempts have been made to include these indices in soil quality assessment programmes.

Land degradation is the manifestation of poor soil health or in other words, unhealthy soils are highly prone to further degradation. According to the latest estimates (2010), around 120 Mha (104 Mha arable land) of the country is subjected to land degradation due to soil erosion through water and wind, chemical degradation (salinity, alkalinity, acidity) and physical degradation (water logging). There are nearly 25 Mha of cultivated lands with pH less than 5.5. These are critically degraded. Productivity of these soils is very low due to deficiencies of P, Ca, Mg, Mo and B and toxicities of Al and Fe. It is a universal truth that a healthy soil produces a healthy plant, and health of human and animals depends on the health of soil. As compared to human beings, livestock are more susceptible to deficiency of micronutrients. Soil composition dictates nutrient content of the food, feed and fodder.

Soil health management is a widely studied area in Soil Science across the country, but most of the researches are limited to soil fertility and nutrient management. A lot of basic, strategic and applied research work has been carried out in different agro-ecological regions during the last five decades, leading to a better understanding of soil health and development of viable technology packages based on sound soil and nutrient management strategies. Soil health and quality have remained matters of a great concern for the Government of India. Government has made huge investments in arresting soil degradation and improving the declining status of soil fertility in the country. For this purpose several developmental schemes have been implemented. In 2015, National Mission on Soil Health Card has been launched to provide soil-test-based fertilizer recommendations to all the farmers across the country. However, shortage of trained technical manpower is a major limitation coming in way of the successful implementation of these programmes. Soil health management at the country-scale is not possible without partnerships and networks. At present these programmes are being implemented through the partnerships among the Department of Agriculture and Cooperation and Farmers' Welfare, Department of Fertilizers, Department of Agricultural Research and Education (DARE) and others. There is an urgent need of fostering strong partnerships and networks for successful implementation of the soil health management programmes at the country-level.

Skill development, capacity building and trainings on soil health management are essential with evolution of new tools and techniques. Use of information and communication technologies may add value to the relevance of these programmes and make them more meaningful. Therefore, strong hands-on training network should be made an essential part of the successful soil health management programmes. Major policies of Government may be given a serious relook in view of country's changing priorities and to harness the fullest potential of mega initiatives like soil health mission. Some of the important policies, which may be relooked into include diversion of agricultural lands for other competitive uses, nutrient-based subsidy (NBS) and its impact on soil health, efficient use of fertilizer nitrogen etc.

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Efficient management of municipal bio-waste in India for sustaining productivity and soil health

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Introduction

India has achieved remarkable growth in food production in the post-green revolution period by increasing from 90 MMT in 1969-70 to 247 MMT during 2013-14. But now we are witnessing the second generation problem like soil fatigue due to intensive cultivation and imbalanced use of fertilizers, declining soil organic carbon, lowering of water table, climate change and lack of plant genetic ideotype. Of the 141 million ha of net sown area in the country, 78 million ha is rainfed, which is being regarded as a high risk venture. Moreover soil of these regions are highly deficient in plant nutrients such as nitrogen, phosphorus, zinc, copper, manganese, boron, molybdenum, zinc and others. Unabated land degradation, soil health and productivity, soil carbon, water resource and related problems are posing a great handicap in enhancing the productivity of various crops. Most recent technological approach namely Conservation Agriculture is largely based upon soil carbon and resource management on a long-term basis is being tried. In particular, Integrated nutrient (INM) and farming system (IFM) management approaches for higher resource use efficiency are also a part and parcel of this concept. The main idea is to enhance productivity of crops and thereby increasing income and employment generation in rural areas. Wherever possible and market forces allow growing of high-value-low volume crops such as horticultural, medicinal aromatic, spices, plantation etc. may be cultivated. Even inclusion of livestock agroforestry and fisheries-based enterprises are necessary for supporting livelihood through simultaneous production of food, fodder, firewood and energy. Thus there is a need for redesigning support system and incentives with a better focus on natural resource management technology centered soil upon health and hi-tech agriculture which will ultimately contribute towards achieving self sufficiency and safety-nets in agricultural system. Most of the Indian soils are deficient in nitrogen and phosphorus and it has been observed that soils are showing deficiency of sulphur, zinc, iron, boron molybdenum and other nutrients depending upon soil type, agro-climatic conditions. Naturally use of organics in agriculture is vital for heterotrophic organisms for providing energy and new cell formation. The cells of most micro-organism commonly contain approximately 50 per cent carbon. Since, Indian soils are largely deficient in organic carbon, the hindering micro-biological activity and their stagnating crop productivity due to intensive cropping system. Not only the food production is being affected but also soil degradation is taking place. It is therefore, vital for us to consider efficient utilization of all available organic wastes and meet the challenges for 2nd green revolution in Agriculture.

Sustainable agriculture

The rapidly increasing population in India, shrinking good quality land resource by urbanization and industrialization and environmental degradations have been a cause of concern for developing an agricultural system to be sustainable. Worldwide, this aspect is being scientifically discussed and examined. The Food and Agricultural Organization (FAO) of the United Nation, International Research Institutes and National Agricultural Research System (NARS) are deeply concerned of declining soil fertility and productivity, climate change, shortage of irrigation water, depletion of mineral resources and high cost of energy and inputs.

Types of rural and urban wastes

Following types of wastes are available from

(i)	Human and Animal	Urine and excreta, bones and dead bodies
(ii)	Agricultural Waste	Crop residues, dried plants, wild plants, trees pruning and felling
(iii)	Environmental waste	Rainwater, wind and sunshine
(iv)	House-hold waste	Kitchen waste, paper, plastic bottles, iron goods, sewage and sludge, used clothes and furniture and rags rubber coal
(v)	Industrial waste	Marble wastes, distillery effluent, spent wash, plastic coir pith, press mud etc.
(vi)	Building and Road Sweeps	Stones, broken brick, silt, sand, paints, broken sanitary filling etc.
(vii)	Garden, Park Waste	Largely hard wooden, plant origin material
(viii)	Mandi Waste	Vegetables
(ix)	Electronic waste	
(x)	Hospital waste	

Municipal waste

India's population has expanded from 342 million in 1947 to 125 billion in 2014. Town planning, waste management, public hygiene and public health had not received due and required attention. Continued urban migration/ congregation of poor in city slums without safe water supply, toilets and sanitation have aggravated the problem, particularly that of sanitation. Thus urban solid wastes management (USWM) has remained one of the most neglected areas and also lack of land for safe disposal, financial and infrastructural support have been apathetic at all levels namely people's participations, local urban bodies, state and central governments. In most cities nearly half of SWM generated remains unattended. This gives rise to unsanitary conditions which has resulted in an increase in morbidity and mortality especially that of children, women and senior citizens. Periodic out breaks of food borne, water borne and vector borne diseases occur in all cities. It is to be appreciated that our Hon'ble Prime Minister Sh. Narendra Modi Ji has launched "Swachha Bharat Abhiyan" on a large scale in the country. In fact, management of solid urban waste is not a problem, it is an opportunity if we handle this with a "ZERO" Garbage Concept". Scientifically and Systematically handle this vital asset and convert this problematic garbage into "Black Gold". At ICAR Indian Institute Soil Science, the technology developed can be easily implemented, if there is a will to do so. This technology is technically feasible, economically viable, socially acceptable and ecofriendly. The aim of our present Govt of India is: "City Clean, Field Green target" shall be achieved.

The National Green Tribunal (NGT) has reported that Delhi is staring at a major management crises in 12th November 2014. Following are the major recommendations:

1. Delhi has to start segregation of garbage at source
2. 50% of waste is fit for composting
3. 20% of the waste would reach landfills after segregation
4. Delhi waste generation is 9,200 tonnes daily
5. Use manure for plants
6. Collect all paper and cardboard trash and sell them
7. Plastic and glass recycling
8. Avoid sachets, aluminium foil etc.

In other words, segregation at source, do recycling as much as possible, ensure sale of manure, check ground, air, water pollution at landfills and no burning of garbage for waste to energy plant. The high powered committee on Urban Solid Waste Management in India planning Commission, Government of India 1995, reported that such orders are also to be executed in other metropolitan cities. However, urban solid waste from Indian cities has low calorific value and high moisture content with high percentage of non-combustible material, hence it is generally unsuitable for thermal technologies.

Systematic composting process

During composting, biodegradable segment after being well segregated is decomposed by diverse microbes in the thin liquid films (biofilms on the surface of the organic particles). The composting process under optimal conditions can be divided into 7 stages:

Segregation of the garbage is most vital component of this process. This heterogeneous and unsegregated waste is a mixture of biodegradable and non-biodegradable materials consisting of about biodegradable compostable(35-42%), plastics(2- 5%), rubber and leather (0.5%), Rag (2.8%), glassware 4.5%, stone/soil (31%), Tyre/tubes (3.3%), and others (ceramics, earthen pots etc., 14 %).

To the biodegradable material, add microbial community including mesophilic fungi, and keep moisture at 55-60% by volume and ensure aerobic condition. The proliferation of fungi and bacteria raise the temperature to 40° C. An increase in pH is favourable for bacteria that subsequently dominate over fungi in the few hours or days. Actinomycetes develop more slowly than most bacteria and fungi and are ineffective competitors when nutrient levels are high.

Major micro-organisms in the mesophilic stage

Bacteria	Fungi
<i>Bacillus sps.</i>	<i>Aspergilus</i>
<i>Cellumonas</i>	<i>Fusarium</i>
<i>Thiobacillus sps.</i>	<i>Trichoderma</i>
<i>Pseudomonas sps.</i>	<i>Mucor</i>
	<i>Helminthosporium</i>

Thermophilic phase

This phase is highly important not only for decomposing cellulose but also for killing the pathogenic and disease contaminants. Thermophilic phase of composting is initiated by microorganisms metabolizing proteins, increasing liberation of ammonium and causing subsequent alkalinization. Whereas the numbers and species diversity of thermophilic organisms in particular actinomycetes and fungi increases with increasing temperature from 40-60° C.

Major Organisms in the mesophilic stage

Bacteria	Actinomycetes
<i>Basillus sps.</i>	<i>Micro-monosperma</i>
<i>Strepto thermophilus</i>	<i>Nocardia</i>
<i>Fungi</i>	<i>Streotomyces</i>
<i>Humicolla</i>	<i>Termospora</i>
<i>Absidia</i> <i>Chectonium</i>	<i>Themopolyspora</i>

Cooling/ second mesophilic phase

After the thermophilic process ceases due to depletion of substrate the re-colonization of microbes take place and the bacteria decrease by 1- 2 orders of magnitude. Their function gets involved in hydrogen, ammonium nitrite and sulphuroxidation, nitrogen-fixation, exopolysaccharide production and

nitrite production from ammonium under heterotrophic condition. High numbers of diverse mesophilic and thermotolerant actinomycetes and yeast reappear. Fall of temperature lower water content and their ability to attend either degrade natural complex polymers (e.g. cellulose, hemicelluloses, lignocelluloses, lignin) and favour mesophilic and thermophilic-tolerant fungi during the cooling phase.

Maturation phase

During the maturation phase main activity which takes place is degradation of the more resistant compounds and transformed into humus. These compounds are lignin, lignocellulose and other recalcitrant compound of tree bard, yard wastes, agricultural hardy wastes etc. Paper may contain 20% of lignin. Most of the fungi are active and through enzymatic action attack at a low water content.

Humus synthesis phase

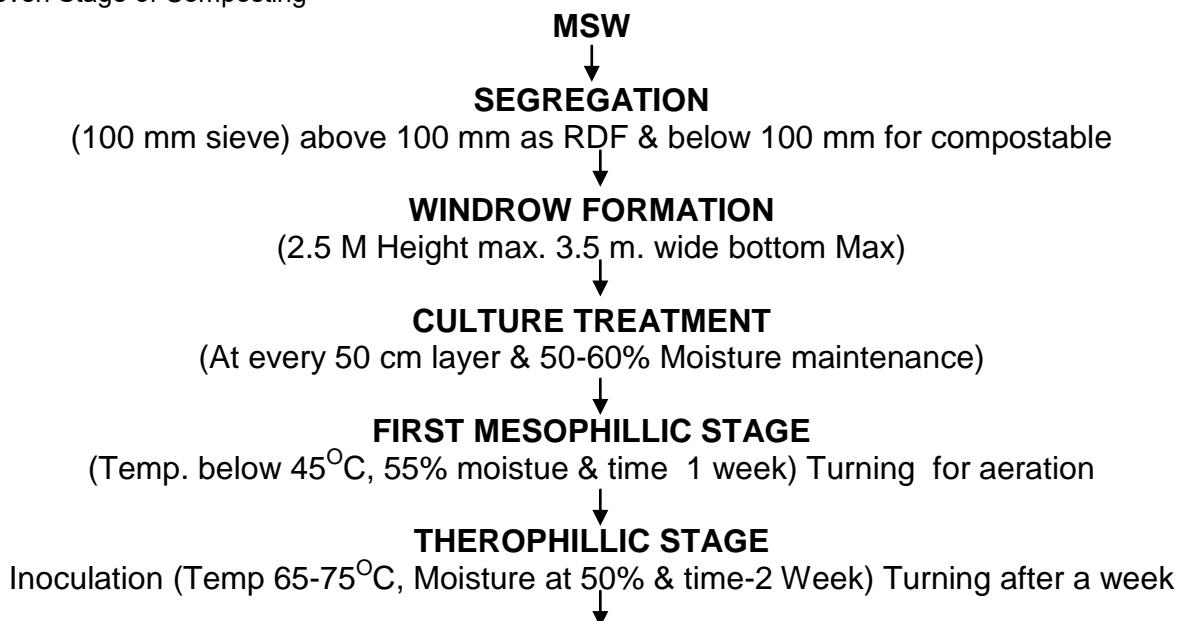
The end product of composting is humus formation, in which compounds of natural origin are partially transformed into relatively stable substances. Humus is a black to dark brown compound, which has high molecular weight, very high CEC and is a store house of plant nutrients.

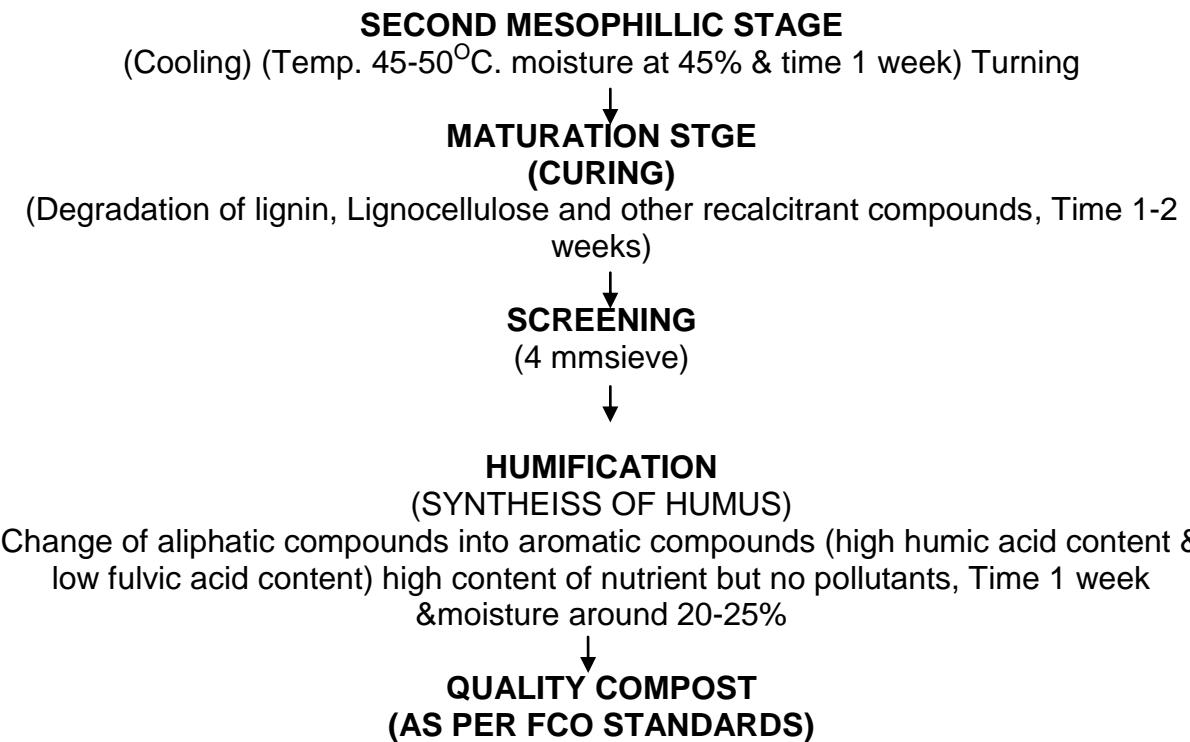
Mature humified compost is characterized by

- high content of stable organic matter rich in aromatic moieties.
- refeeding of soil with humus into soil microbes.
- high nutrient supplying capacity
- support better plant growth and health
- minimum content of pollutant

Packing and bagging

The packing material should be such that certain amount of air inflow and release of CO and other 2 gases may take place. The moisture percentage should be about 15%. No overloading of bag at each other should be strictly observed. The packed bags must be used within a period of three months. For better understanding, the following steps of FLOW CHART is a must for the production of quality compost. For preparing of good quality compost from MSW it is necessary for the organics to go through "Seven Stage of Composting"





To achieve this above mentioned time frame along with essential inoculants and aeration shall be kept in mind. Indigenous & Effective Microbial culture as inoculants shall be effectively used. Turning for aeration should be ensured. This time frame of 8-10 weeks is sufficient for production of compost from biodegradable segment of MSW. In case of agricultural waste recycling about 100 to 115 days is required for production of mature compost. Segregation step is not required for recycling of agricultural waste.

Constraints

Since during scientific processing and composting the labour, energy and culture cost are greatly involved for the preparation and manufacturing of the good quality compost, the cost become unaffordable by small and marginal farmers. The Government of India and State Government should bear 50% of its cost of processing and marketing. If it is not implemented this is a handicap. Total subsidy will be around Rs.5,000 crore a year, while the Government of India is bearing Rs.65,000 crore subsidy each year.

Biodegradable waste

Biodegradable organic wastes such as crop residues, agro industrial organic wastes, city garbage and forest litter have wide C/N ratios ranging from 80 to 110, and low concentration of available plant nutrients particularly N, P and K. On the basis of crop production levels, it is estimated that ten major crops (rice, wheat, sorghum, pearl millet, barley, finger millet, sugarcane, potato tubers and pulses) of India generate about 792 Mt of crop residues, in which 201 million tonnes is actually available that has nutrient potential of about 4.865 million tonnes of NPK. The potential availability of all animal excreta is about 792 million tonnes of which 287.45 million tonnes is actually available that potentially supply 3.474 million tonnes of plant nutrients.

Indian cities will be among the most densely populated among the cities of the world. Metropolitan cities of India generated about 64.8 Mt of city refuse during 2010. These had a potential to prepare 9.1 Mt of compost. The production of MSW is expected to increase to 107 Mt by 2030. Big cities like Delhi, Mumbai and Kolkata with population greater than 10 million are generating 6,000 to 7,000 tonnes of MSW

daily. Other cities such as Bhopal, Nagpur, Chennai, and Bangalore are producing about 3,000 tonnes of MSW/daily. Urban Solid Waste is one of the most neglected areas of urban development in India. In most cities nearly 2/3rd of solid waste generated remains unattended. It is therefore imperative to improve urban solid waste management, so that the adverse health and environmental consequences of the rapid urbanization are minimized. Although about 40% of matter in MSW is considered to be biodegradable, only 14% (9.1 Mt) of the MSW were composted in 2010. It is a paradox that organic solid wastes generated by agriculture, domestic, commercial and industrial activities are often indiscriminately disposed off on the land on nearby areas of the country. The disposal pattern of wastes also varies from season to season. However, under ordinary conditions of storage, there are tremendous losses of plant nutrients either by burning, using as fuel cake, leaching or volatilization when manures remain exposed to sun and rain. Thus, proper composting is a microbiological, non-polluting and safe method for disposal and recycling of these wastes by converting them into organic fertilizer. It is also known that the composts produced in India is of nutritionally low-grade quality. If a sound technology is adopted to improve the quality of compost in the shortest possible time, even farmers can prepare the compost easily and improve its nutritional quality by an addition of cheap amendment such as rock phosphate.

Indian rock phosphate

In India, about 260 million tonnes of rock phosphate deposit has been estimated at present. Rock phosphate (11-32 % P₂O₅) is available in different states of India such as, Udaipur (Rajasthan), Jhabua (Madhya Pradesh), Visakhapatnam (Andhra Pradesh), Purulia (West Bengal), Mussori (Uttaranchal) etc. Low-grade rock phosphate is used as a source of P for crop production. The other amendments such as pyrites (22% Fe and 22.5 % S), is available in large scale at Amjer (Jharkhand).

Potential of rock phosphate use in India

Out of the total reserves of 305.3 million tonnes of Rock phosphates in India, around 1.9 million (FAI, 2012-13) tonnes are mined every year. Out of this, around 1.7 million from Jhamarkotra, Rajasthan is being applied as largely in red and yellow soils. Besides, around 7.3 million tonnes of rock phosphates are imported every year, mainly from Jordon, Egypt, and Morocco. Around one million tonnes of rock phosphate shall be used for making of enriched compost by pooling from indigenous and imported rock phosphates. It is because the rock phosphate which is hitherto being used as direct application can be made more efficient in terms of P nutrient supplier when supplied through enriched compost.

Potential of enriched compost use in India

For 1000 kg of enriched compost production by heap method, the total quantity of biodegradable waste, fresh cow dung, urine, rock phosphate, pyrites, urea, inoculants and soil, will be 5000, 200,50, 328, 120, 13, 100, and 20 kg respectively. As per conservative estimation, the availability of crop residue is 201 million tonnes, and the availability of fresh cow dung is 72 million tonnes out of 144 million tonnes since a large part has to invariably go in the making of dung cakes. Hence, as per the above mentioned treatment, it is the rock phosphate which is a vital input for the manufacture of enriched compost. With an assumed value of one million tons of rock phosphate that can be made available for making enriched compost, 1.0 million of enriched compost shall be produced.

Potential to substitute inorganic P fertilizers in India

The computation showed that the approximate enriched compost generated would be about 10 million tonnes per year that would be equivalent to about 1.89 million tonnes of P₂O₅ (enriched compost content about 6.30 % P₂O₅), which is equivalent to 11.81 million tonnes of single supper phosphate (SSP) and 3.94 million tonnes of diammonium phosphate (DAP). It is stipulated that the phospho-compost can substitute 24% of chemical fertilizers in terms of P requirement. This would result in to reducing the subsidy on P fertilizers to about 24%.

Composition of enriched phosphocompost

After 110 days of decomposition (crop residues) enriched compost should contain 3.2 to 4.2% P and 1.5 to 2.3 % N. The content of NH₄-N and NO₃-N would be 0.12 to 0.54 and 0.28 to 0.90 g kg⁻¹ respectively. Citrate-soluble P in phosphocompost ranged from 0.23 to 0.98 %. Because of the addition of rock phosphate, pyrites and bio-solids the manurial value is markedly enhanced as compared to FYM and ordinary compost. Since Indian soils are developing multi-nutrient deficiencies, an effort has to be made to enrich manurial value particularly in respect of phosphorus, sulphur and N content.

Scope of enriched phosphocompost use in India

It would be more economical to apply the enriched compost in those soils that are low in available organic carbon. Such soils exist in large parts of Alluvial soil zone i.e. in most of the Indo- Gangetic plains. However, once the manufacture starts, even the imported rock phosphates can be used in making enriched composts and used in black, red and yellow soils of the country in later years

Field trials results and economics of enriched composts

- In a three-years field study on soybean-wheat system, application of 100% NPK through enriched compost to soybean and 50% NPK to succeeding wheat produced the highest yield and saved 25 kg N and 39.2 Kg P/ha.
- A five years-field study on Vertisols revealed that compost application @ 5 t ha⁻¹ in combination with 75% NPK to soybean followed by 75% NPK applied to wheat produced higher productivity in soybean-wheat, sorghum-wheat and soybean +sorghum-wheat system compared to 100% NPK treatment and saved 37 kg N, 30 kg P and 15 kg K.
- To improve soil biological activities phosphosulpho-nitro compost along with chemical fertilizer application is a better option compared to inorganic fertilizer alone.
- Phospho-sulpho-nitrocompost contains relatively higher amounts of available plant nutrients compared to conventional compost.
- Thus, phospho-sulpho-nitro compost helps to produce higher yields of crops, quality of produce and maintain fertility status of soils. The use of enriched manure in field crops is also economically viable and safe to the environment. The residual effect and also improvement in soil quality are other aspect of worth consideration.

Economic advantage of MSW compost

Enriched MSW compost can be prepared in 75 days. Enriched MSW compost contains relatively higher amounts of available plant nutrients as compared to ordinary (uninoculated) MSW compost. The heavy metals can be reduced by improving the quality of compost. Thus, microbial enriched compost helps to produce higher quality manure, shorten the usual period of composting from 6 months to 2.5 months. The prospect exists to enrich compost in urban peripherals and use it in crop production and the compost is safe to the environment.

Indiscriminate exploitation of natural resources without considering the carrying capacity and non-judicious use of agriculture input to fetch higher production had generated serious problem on sustaining agricultural productivity and soil quality. Degradation of quality of soil through organic matter depletion, nutrient losses, and decrease in soil organisms etc., the process may be reversed when cultivation is managed and these soil health attributes may begin to change. Thus, inter disciplinary and participatory mode, collaboration with Central government (ICAR), NonGovernmental Organization and farmers participatory approach to recycle the MSW for improving nutrient use efficiency, sustaining productivity and soil health under farmers' fields is urgently needed.

Conservation of microbial biodiversity: a key to sustainable soil health

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Soil biodiversity

Biodiversity is usually defined as the variety and variability of living organisms and the ecosystems in which they occur. For many people the term biodiversity usually means animals or plants; however, the soil habitat harbours a huge number of different microbial species. Whereas animal and plant ecologists can count numbers of different species through (relatively) easily identifiable traits, it is difficult to do this with bacteria and fungi. Until recently, microbial identification usually required isolation from soil through growth on standard laboratory media; however fewer than 1% of bacterial species and an unknown percentage of fungi could be recovered in this manner. The variety of life in the soil encompasses not only plants and animals but also the invertebrates and micro-organisms that are interdependent on one another and the higher plants they support. Soil biodiversity encompasses all organisms that live in the soil, whether they are single-cell organisms or multi-cell animals or plants, which can be classified using traditional taxonomic techniques or genetically via unique DNA or RNA. It also embraces an immense ecological diversity manifested through behaviour patterns and feeding or habitat preferences. The combination of all these aspects is expressed in the functional diversity of soil organisms. The number of species (taxonomic diversity) clearly encompasses an important part of an ecosystem's diversity and this is controlled by the genetic diversity, which can be greater than the number of recognised species. Several species may have the same functions, resulting in what might appear to be functional redundancy. Equally, some species may interact to perform functions not possible by any single species. Biodiversity is therefore the interaction of all these elements. The diversity of soil organisms is more extensive than any other environment in the world when all living forms are considered.

With respect to the impacts of agricultural management on soils, soil (microbial) biodiversity is generally linked to soil fertility (FAO, 2001). Attention has focused on identifying possible bio-indicators, specifically for microbiological bio-indicators, which are suitable for defining soil quality or soil health (Doran and Safley, 1997). The definitions for soil quality or soil health are often interchangeable, whereby soil health comprises more the biological components of soils, i.e. the ability of a soil to perform functions that are required for the biological components of an ecosystem (Dick, 1997). Pankhurst (1997) in his review assessed the possible link between soil biodiversity, soil functional processes and soil health. Altieri (1999) has proposed a relationship between soil biodiversity and soil fertility with respect to crop production management.

Soil is rich in biodiversity

The soil biota contains representatives of all groups of micro-organisms, fungi, bacteria, algae and viruses, as well as the microfauna such as protozoa and nematodes. Soil algae and protozoa, like higher plants and animals, can be identified by their morphology. Fungi and bacteria, however, require more extensive biochemical and genetic analysis to enable identification. It has been estimated that only between 1 and 5% of all micro-organisms on Earth have been named and classified. A large proportion of these unknown species is thought to reside in the soil (Table 1).

The new molecular techniques Torsvik and co-workers used reassociation kinetics of single-stranded DNA to show that there is considerable genetic diversity among the microorganisms that are found in soil (Torsvik et al. 1998). They estimated that a pasture soil sample contained about 3,500–8,800

genome equivalents. This could result in approximately 10,000 different species of equivalent abundance. This immense diversity presents a challenge for researchers who are attempting to completely describe microbial communities (Keller and Zengler 2004).

Table 1: Number of known and estimated total species globally of selected groups of organisms (Coleman et al. 2005)

Group	Known species	Estimated total species	Percentage known
Vascular plants	220 000	270 000	81
Bryophytes	17 000	25 000	68
Algae	40 000	60 000	67
Fungi	69 000	1 5000 000	5
Bacteria	3000	unknown	unknown
Viruses	5000	130 000	4

Despite this extraordinary array of life forms, the taxonomic knowledge and also the functions of soil organisms is incomplete, with many genera that are neither identified nor classified at the species level. This lack of knowledge is particularly marked for tropical soils, which are considered at greatest risk from changes resulting from agricultural intensification with its consequent loss of biodiversity (Giller et al. 1997; Decaëns and Jiménez 2002).

The high species and functional diversity in soils is well appreciated but its root causes still remain unknown. Soil microbial diversity and functioning are a product of soil, climate and plant factors. The belowground environment provides numerous niche axes in the hyperspace, concerning numerous microhabitats, microclimatic properties, soil chemical properties, and phenologies of the organisms themselves. Soils exhibit a high degree of spatial heterogeneity, both vertically and horizontally. Soil properties can vary within fields as much as across whole landscapes. If we consider soil at the microscopic scale, the spatial heterogeneity is amplified further. Soil is a complex network of pores ranging in size from 0.2 microns to 2mm. Many of the smallest organisms are protected from predation in pores with a diameter of 2-100 microns (Grundmann, 2004). Many of the important chemical and physical properties of soil, such as pH and oxygen status, can vary over a short distance, e.g. from root surfaces to bulk soil and from inner to outer surfaces of a soil crumb. If we couple the spatial heterogeneity of potential living spaces with the diversity of food and energy sources available, that are also subject to temporal variation in moisture and temperature, it is not hard to imagine that there is a place for all types of organisms.

Soil biodiversity and ecosystem functioning

Soil micro-organisms are clearly vital to sustaining the biosphere and functioning of ecosystems and, as a consequence, can be used for monitoring and predicting environmental change and pollutant impacts. Since soil functionality depends so much on the activity of micro-organisms, measures of the activity, biomass and diversity of soil micro-organisms, including the presence and health of root dwelling symbionts, have often been proposed as indicators of soil quality. Ecosystem functions provided by microbes are the transformation of inorganic carbon into biomass by primary producers, nutrient regeneration and cycling, conversion of organic matter including humus that would otherwise be lost from the food web into living biomass, regulation of biogeochemical cycles and consequently climate (Table 1).

Microbial functions such as degradation of organic matter (including oil or pesticides) require complex metabolic pathways. Microorganisms account for the main portion of the global metabolism (and biomass). Thus, also for functioning, the microorganisms might be the unseen majority. The 'insurance hypothesis' assumes that there are many species in an ecosystem, which can perform the same or very similar functions (Naeem and Li, 1997). These redundant species can take over ecosystem functions once a dominant species is lost or low in performance. This insurance due to redundancy of species may result in a resilience of ecosystem functions, although biodiversity may vary. Resilience can also mean

the resistance of a system in terms of diversity and function against disturbances. Periodic variations such as due to seasons can be described as dynamic equilibrium. The relationship between diversity and ecosystem functioning

Table 1: Essential functions performed by the different members of the soil biota

Functions	Organisms involved
Maintenance of soil structure	Earthworms, arthropods, soil born fungi, mycorrhizas, plant roots, and some other microorganisms.
Regulation of soil hydrological processes	Earthworms, arthropods, soil born fungi, mycorrhizas, plant roots, and some other microorganisms.
Gas exchanges and carbon sequestration	Most invertebrates like earthworms, arthropods, and plant roots.
Soil detoxification	Mostly microorganisms and plant roots, some C protected in large compact biogenic invertebrate aggregates.
Decomposition of organic matter	Various saprophytic and litter feeding invertebrates (detritivores), fungi, bacteria, actinomycetes and other microorganisms.
Suppression of pests, parasites and diseases	Mycorrhizas and other fungi, nematodes, bacteria and various other microorganisms, collembola, earthworms, various predators.
Sources of food and medicines	Plant roots, various insects (crickets, beetle larvae, ants, termites), earthworms, vertebrates, microorganisms and their byproducts.
Symbiotic and asymbiotic relationships with plant and their roots	Rhizobia, mycorrhizae, actinomycetes, diazotrophic bacteria and various other rhizosphere microorganisms.
Plant growth control (positive and negative)	Direct effects: plant roots, rhizobia, mycorrhizas, actinomycetes, pathogens, phytoparasitic nematodes, rhizophagous insects, plant growth promoting rhizosphere microorganisms, biocontrol agents. Indirect effects: most soil biota.

(Source:<http://www.fao.org/ag/agl/agll/soilbiod/docs/SB-brochure-sept.pdf>)

and its contribution to the resistance of ecosystems are important issues in the ecology. It has been suggested that those soils harbouring a greater diversity of microorganisms are more likely to be resilient to stresses such as, for example, hydrocarbon (e.g., petroleum, diesel or oil spillage) or heavy metal contamination, or long term water-logging. Human land use and agricultural practices have been identified as the most important factors affecting biodiversity.

High intensive agricultural managements are negative for soil biodiversity. Using molecular proves, Patra et al. (2005) has observed in a semi-natural grassland ecosystem that the composition of the ammonia oxidizing community significantly differed between the intensive and light grazing sites (Fig. 1). Four DNA bands were characteristic of the extensive treatment at both downslope and upslope locations, whereas two other bands were characteristic of the intensive treatment at both downslope and upslope locations. In this case, a negative correlation was observed between nitrification rate and the number of bands identified from DGGE profiles (Fig. 1). This indicates that samples exhibiting the highest activity rates also exhibited the lowest community complexity. This could be explained by selection, under intensive grazing, of only a few strains that may be favored by the high, grazer-induced N recycling and labile N availability. For example, ammonia oxidizers are either sensitive to or tolerant to high concentrations of ammonia, potentially leading to selection of the latter group in soils with persistent high

ammonia supply, increasing their relative abundance and decreasing the community complexity. In addition, changes in nitrification enzyme activity were correlated with changes in the occurrence of a few DGGE bands. Results suggest that changes in nitrification enzyme activity could be partly due to changes in the composition of the ammonia-oxidizing community.

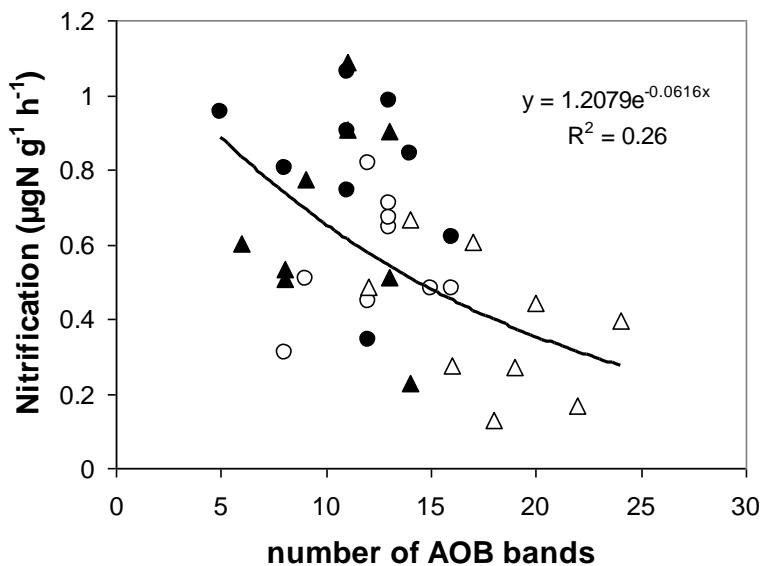


Fig. 1. Relationship between nitrification enzyme activity and the number of bands detected from genetic fingerprinting of the ammonia oxidizing community

(●: intensive grazing downslope; ○: light grazing downslope; ▲: intensive grazing upslope; Δ: light grazing upslope). The structure of the ammonia oxidizer community was analyzed by PCR-DGGE (denaturing gradient gel electrophoresis) of the 16S rRNA gene amplifications of extracted soil DNA (Patra et al. 2005).

Soil biodiversity and soil health

Soil health can be defined as the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity and maintain water quality as well as plant, animal and human health. The concept of soil health includes the ecological attributes of the soil, which have implications beyond its quality or capacity to produce a particular crop. These attributes are chiefly those associated with the soil biota: its diversity, food web structure, activity and the range of functions it performs. Soil biodiversity *per se* may not be a soil property that is critical for the production of a given crop, but it is a property that may be vital for the continued capacity of the soil to produce that crop (including pastures and trees). Indicators of soil health are required to account for multiple dimensions of soil functions, in terms of agricultural productivity, food security and sustainable resources and ecosystem management, and the multiple physical, chemical and biological factors that control long term bio-geochemical process, and their variation over time and space. Of primary importance is the contribution of soil organisms to a wide range of essential services and to ecosystem functioning by acting as the primary driving agents of nutrient cycling, enhancing the amount and efficiency of nutrient acquisition by the vegetation and enhancing plant health, through maintaining the hydrological regime and soil physical structure, through regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emission, as well as pedogenesis, the continuous building and restoration of the soil.

Soil biodiversity against biotic stress and disturbance

Many soil organisms are detrimental to plant production and thereby reduce optimum resource utilization. Every year agricultural production suffers by million of rupees due to moles, rodents, snails, slugs, termites, ants, beetles and nematodes. Several species of bacteria and actinomycetes can cause plant diseases, but most damage is caused by fungi, which account for most soil-borne crop diseases, such as wilts, root rot, clubrot, and blight. Therefore, resistance against outbreaks or stress of pests and diseases and resilience from disturbance is of particular importance in agriculture. General suppressiveness of soils is the inhibition of pathogens as a result of a high total microbial biomass combined with a very intense competition for carbon and/or nutrients. An example of the role of soil biodiversity on disease suppression can be given from a long-term experiment, where fields were subjected to different treatments: species rich permanent grassland, grassland turned 2 years previously to arable land under rotation or monoculture of maize, and long-term arable land under rotation or monoculture of maize (Garbeva, 2005). The highest suppression of the soil-borne pathogen *Rhizoctonia solani* AG3 on potatoes, planted in small subplots, was measured in grassland turned into monoculture of maize. Using in vitro screening for antagonistic isolates against *R. solani* AG3, higher numbers of such isolates were found in soil under permanent grassland and under grassland turned into arable land than in soil under arable land. Using the Shannon–Weaver index for DGGE bands of the soil microbial community, highest disease suppression was found in plots with highest soil microbial diversity.

Impact of land-use changes on soil biodiversity

Under favorable conditions, one tenth of the organic matter in a soil is made up of soil animals. Thus, a layer of 10 cm of a hectare of soil with 1% organic matter contains roughly 1500 kg of soil fauna. This equals the weight of 3-4 cows. Sometimes even small changes in the soil environment may have a large influence on the overall soil diversity and community structure. Some of the environmental factors that are known to influence community composition are organic contaminants, heavy metals, pesticides, etc. Physical parameters of the soil, such as particle density, permeability, porosity, moisture content, mineral composition and vegetation cover, are all factors that can influence microbial composition (Sessitsch et al. 2001; Girvan et al. 2003; Kowalchuk et al. 2002). There are now well-documented cases to show that conversion of natural vegetation to other land-uses, including agriculture, results in change in the diversity of the soil community. Changes in the below-ground biodiversity are often thought to track those of plants, although there is evidence that the soil community may be more functionally resilient than the above-ground biota. As land conversion and agricultural intensification occur, the planned biodiversity aboveground is reduced (up to the extreme of monocultures) with the intention of increasing the economic efficiency of the system. This impacts the associated biodiversity of the ecosystem –eg., micro-organisms and invertebrate animals both above and below ground - lowering the biological capacity of the ecosystem for self-regulation and thence leading to further need for substitution of biological functions with agrochemical and petro-energy inputs.

The sustainability of these systems thus comes to depend on external and market-related factors rather than internal biological resources. The biodiversity of soil under natural vegetation may be taken as a baseline for monitoring changes under varying land-use. The assumption is often made that the consequent reduction in the diversity of the soil community, including cases of species extinction, may cause catastrophic loss in function, reducing the ability of ecosystems to withstand periods of stress and leading to undesirable environmental effects. The detection of critical thresholds for functional change is however still a matter of debate. The high biodiversity within many functional groups of soil organisms has been interpreted as conveying a substantial degree of redundancy to the soil biota and led to suggestions of high resilience.

Managing soil biodiversity

Soil animal and microbial diversity is part of the biological resources of agroecosystems, and must be considered in the management decisions. As indicated in Fig. 2, the main management options comprise tillage, crop rotation (and sequence) and organic matter management. The available literature

indicates that high-input agriculture, particularly tilled agroecosystems with narrow crop rotation/short fallow management, leads to a decrease in species richness and dominance of some species. In contrast, management characterized by rotations, no-tillage, organic amendments and maintenance of non-productive (“natural”) elements leads to an increase in species richness and overall density.

Soil microbial communities are responsible for the cycling of the elements necessary for plant growth. However, the management and use of the soils in turn regulate microbial communities. Therefore, the management of agricultural soils has an impact upon the overall ‘health’ of these communities – sometimes positively and sometimes negatively. It is through the better understanding of these communities that we gain a greater understanding of soil health, and how best to intervene in agricultural systems to make them more productive. Some of the potential management approaches are described below:

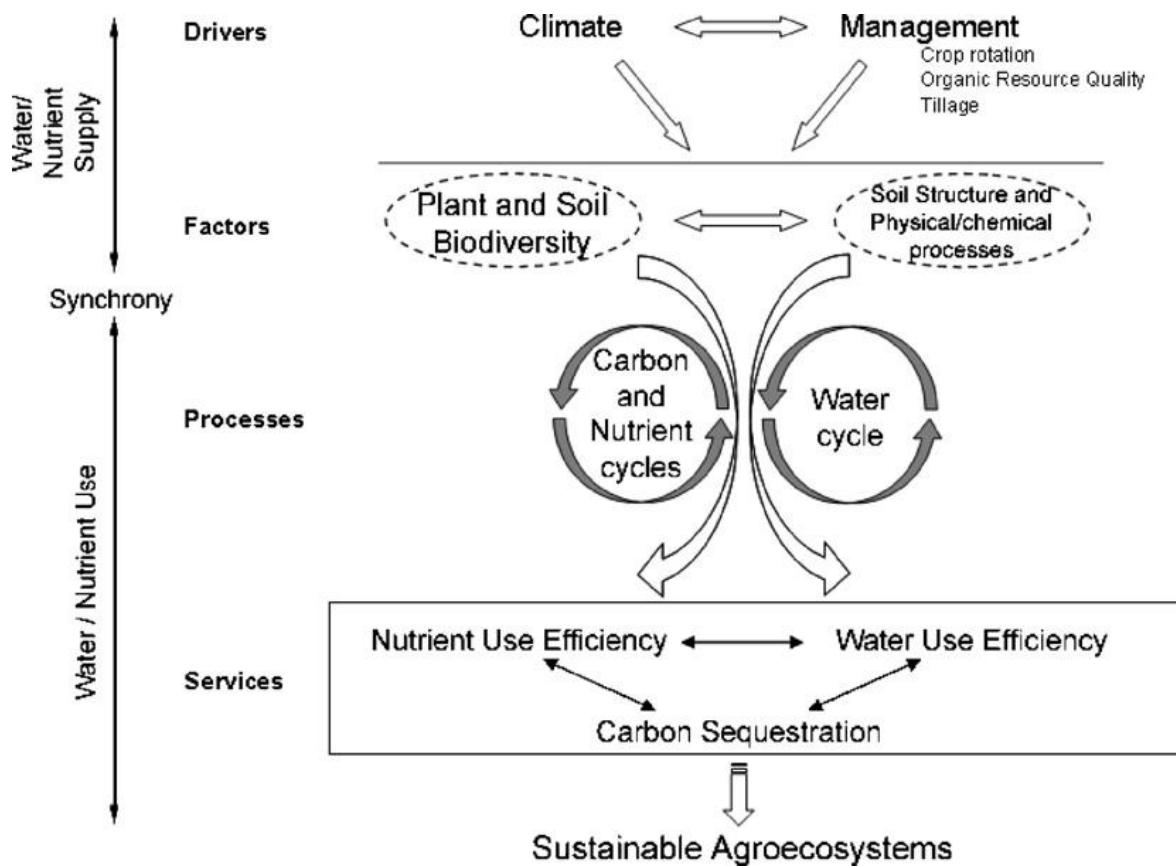


Fig. 2. Conceptual diagram on the relationships between management, plant and soil biodiversity, soil structure and nutrient and water use efficiencies in agroecosystems (Brussaard et al. 2007).

i. Agricultural management practices

There is a wide range of ‘soil bio-technologies’ with the potential to increase and sustain productivity that are currently under-utilised because of the lack of critical evaluation for application in tropical small-scale agriculture. The soil biota may be manipulated by both direct and indirect means. *Direct* management is usually by inoculation with species of soil biota including N₂-fixing bacteria, mycorrhizal fungi, control agents for pest and diseases and beneficial macrofauna such as earthworms. Modern molecular research is also increasing the potential for genetic manipulation of some of these

organisms prior to inoculation. *Indirect* management is achieved through appropriate design and management of cropping system, including the genetic manipulation of the plant component, management of organic inputs and other soil amendments and soil tillage. Indirect approaches probably have the greater potential and relevance to the circumstances of most farmers. The most appropriate practices for conservation of the soil biota are therefore many of those associated with sustainable agriculture. In general terms these include all management practices that maintain soil cover and return organic matter to the soil as well as ensuring that nutrient inputs and outputs are kept in balance. Such practices include: a) Integrated Soil Fertility Management (ISFM) ie the use of both organic and inorganic sources of nutrients rather than either alone; b) The use of legume cover crops and green manures by fallow rotation or inter- cropping; c) Agroforestry practices that provide for deep nutrient cycling and/or return of nutrient to the soil through biomass transfer, fallowing etc; d) The use of conservation tillage rather than continuous deep ploughing; e) Returns of farmyard manures and household wastes, with or without composting; f) Choice of crops and associated plants which have high nutrient use efficiency.

ii. Culture collections

Maintaining cultures of micro-organisms of importance in agriculture is important but in many cases these are under threat due to lack of resources for their maintenance. The most common collections are those of micro-organisms such as *Rhizobia* or mycorrhizal fungi, but earthworm collections for vermi-composting are also available in many places in India. Legislation should address the maintenance of culture collections as well as *in situ* conservation and management.

iii. Promotion of sustainable soil management

There is more widespread acknowledgement of the importance of maintaining soil 'quality' or 'health' i.e. there is recognition of the risk to essential ecosystem services if soil is degraded. Thus the majority of countries make reference to the promotion of sustainable soil management practices. In some cases focus is largely on soil conservation and prevention of erosion but in others more explicit mention is made of the importance of maintaining the organic status of soil. Some approaches are mentioned specifically as sustainable management practices e. g: minimum tillage and organic agriculture. In the long run, greater use of animal and compost manures need to be promoted as a supplement to mineral fertilizers. Integrated pest management strategy should be given high priority. To reduce pollutants reaching water bodies, the run-off water should be filtered through the soil as an integral part of soil conservation structures. Greater attention needs to be given to drought resistant indigenous food plants. Relatively rarely however has rigorous monitoring of the soil biota or its functions been carried out during the above conservation practices.

Conclusions

Soil biodiversity is central to the sustainability of both managed and natural terrestrial ecosystems. Detailed understanding of the insights into its complexity and functions are a great challenge and opportunity for the benefit of any society. Soil biodiversity should be considered as part of biodiversity action plans at a local scale and gradually upscale to regional and country level. We are not currently sure if habitat conservation adequately protects soil diversity and biodiversity and these needs to be given full consideration and research priority, as well. There will be benefits to optimising soil biodiversity in all agricultural areas for supporting crop production, environmental protection, and other ecosystem services. The development of appropriate sampling or monitoring schemes requires standardised methods for sampling and characterisation of soil biodiversity. There is a need of benchmarks or ranges as standards for soil biodiversity in a given soil, under a particular land use, at a particular time and in response to environmental stresses, to interpret and predict the significance of any changes in soil biodiversity. Greater recognition to be given on the intimate relationships between soil biodiversity and the above-ground environment since they are key drivers in maintaining multiple soil functions. This needs to be reflected not just in the monitoring of soil biodiversity but also in the wider context of environmental quality.

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STCR-IPNS: The Indian plant nutrient management strategy for increasing yield and maintaining soil health

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The major challenges in 21st century are food security, environmental quality and soil health. Besides, shrinking land holdings and increasing cost of inputs in India merit adoption of scientific use of plant nutrient for higher crop productivity. The soil fertility and fertilizer use project initiated in 1953 following a study by Stewart in 1947 which was the first systematic attempt in India to relate the knowledge of the soils to the judicious use of chemical fertilizers (Dey, 2014). The soil testing programme was started in India during the year 1955-56 with the setting up of 16 soil testing laboratories under the Indo-US Operational Agreement for "Determination of Soil Fertility and Fertilizer Use". In 1965, five of the existing laboratories were strengthened and nine new laboratories were established to serve the Intensive Agricultural District Programme (IADP) in selected districts. Chemical indices of nutrient availability chosen for use in the soil testing laboratories consisted of organic carbon or alkaline permanganate oxidizable nitrogen, as a measure of available nitrogen, sodium bicarbonate (Olsen's extractant) extractable phosphorus, as a measure of available phosphorus and neutral normal ammonium acetate extractable potassium, as a measure of available potassium. Muhr and coworker describe sets of critical values that characterized the estimates as low, medium or high in a monograph on soil testing in India in 1965. Background research for the choice of critical values consisted of a few pot culture and field experiments with paddy and wheat, carried out in the Division of Soil Science & Agricultural Chemistry at Indian Agricultural Research Institute, New Delhi. Taking a simplistic view of the situation, the differences among soil groups in the range of properties, which influence the susceptibility to absorption by plants of native and applied nutrients, were ignored. The generalized recommendations of fertilizer use developed for the soil testing laboratory area were thought applicable to the medium category of soil testing estimates with an arbitrary adjustment (decrease or increase by 25-50 per cent) for high and low categories of soil test estimates. The ICAR project on soil test crop response AICRP (STCR) has used the multiple regression approach to develop relationship between crop yield on the one hand, and soil test estimates and fertilizer inputs, on the other. Nutrient supplying power of soils, crop responses to added nutrients and amendment needs can safely be assessed through sound soil testing programme. Soil test calibration that is intended to establish a relationship between the levels of soil nutrients determined in the laboratory and crop response to fertilizers in the field permits balanced fertilization through right kind and amount of fertilizers.

STCR: The yield targeting approach

Liebig's law of minimum states that the growth of plants is limited by the plant nutrient element present in the smallest amount, all others being in adequate quantities. From this, it follows that a given amount of a soil nutrient is sufficient for any one yield of a given percentage nutrient composition. Ramamoorthy and his co-workers established the theoretical basis and experimental proof for the fact that Liebig's law of the minimum operates equally well for N, P and K (Ramamoorthy et al., 1967). Among the various methods of fertiliser recommendation, the one based on yield targeting is unique in the sense that this method not only indicates soil test based fertiliser dose but also the level of yield the farmer can hope to achieve if good agronomic practices are followed in raising the crop.

Integration of biofertilisers organics in STCR: The STCR-IPNS system

In this technology, the fertilizer nutrient doses are adjusted not only to that contributed from soil but also from various organic sources like FYM, green manure, compost crop residues and bio-fertilizers like Azospirillum and Phosphobacteria. As the present requirement of chemical fertilizers is 32 million tonnes and only 22 million tonnes of chemical fertilizers are being used, a shortage of 10 million tonnes is occurring and hence combined use of chemical fertilizers along with organics becomes inevitable. In addition to this, addition of organics will help in sustaining the soil productivity and maintaining the soil health by way of improvement of soil physical, chemical and biological properties.

Methodology of STCR-IPNS calibration

It is same as described in previous section. Apart from determination of nutrient requirement (NR) in kg q^{-1} of economic produce, per cent availability of soil available nutrients (CS) as measured by soil tests, and per cent availability of the fertilizer nutrients (CF), and contribution from organic nutrients (CO) were also computed using following equation:

Contribution of N or P_2O_5 or K_2O from Organics (CO)= [Total uptake of N or P_2O_5 or K_2O in organic plots in kg/ha STV of N or P x 2.29 or K x 1.21 in organic plots in kg/ha x mean Cs of N or P_2O_5 or K_2O] / [Amount of N or P_2O_5 or K_2O added as organics in kg/ha]

The calculated parameters are transformed into the fertilizer adjustment equation as given below.
 $F = T \times NR / CF - CS \times STV / CF - CO \times M / CF$, Where,

F = Fertilizer dose of N, P_2O_5 or K_2O in kg ha^{-1}

T = Yield target in $q ha^{-1}$

NR = Nutrient requirement of N, P_2O_5 (P x 2.29) or K_2O (K x 1.21) in 100 /kg for economic produce.

CS = Contribution from soil nutrients in fraction

CF = Contribution from fertilizer nutrients in fraction

CO = Contribution from organic nutrients in fraction

STV = Soil available nutrients [N, P_2O_5 (P x 2.29) or K_2O (K x 1.21)] determined through soil analysis

M = Nutrient content in organic matter [N, P_2O_5 (P x 2.29) or K_2O (K x 1.21)] determined through organic matter analysis x FYM

STCR-IPNSfertiliser prescription equations were developed for Rice-Winter Maize cropping sequence for young alluvium calcareous soils (districts covered Samastipur, Muzaffarpur, Vaishali, Gopalganj, Siwan, Saran, East & West Champaran, Part of Begusarai and Khagaria) of Bihar using three organic sources, viz., Vermicompost, Vermicompost + Azotobacter and Vermicompost + Azotobacter + PSM. The pooled prediction equations are given below:

Only Vermicompost

Pooled prediction equation of Rice:

$$\begin{aligned} FN &= 6.38 T - 0.63 SN - 1.42 ON \\ FP_2O_5 &= 1.33T - 3.07 SP - 0.45 OC \\ FK_2O &= 1.77 T - 0.41 SK - 0.53 OK \end{aligned}$$

Pooled prediction equation of Winter Maize:

$$\begin{aligned} FN &= 2.91 T - 0.22 SN - 0.46 ON \\ FP_2O_5 &= 0.77 T - 1.23 SP - 0.18 OP \\ FK_2O &= 1.47 T - 0.26 SK - 0.38 OK \end{aligned}$$

Vermicompost + Azotobacter

Pooled prediction equation of Rice:

$$\begin{aligned} FN &= 5.36 T - 0.63 SN - 1.81 ON \\ FP_2O_5 &= 1.49T - 3.56 SP - 0.70 OP \\ FK_2O &= 2.10 T - 0.72 SK - 0.79 OK \end{aligned}$$

Pooled prediction equation of Winter Maize:

$$\begin{aligned} \text{FN} &= 2.53 \text{ T} - 0.21 \text{ SN} - 0.72 \text{ ON} \\ \text{FP}_2\text{O}_5 &= 0.71 \text{ T} - 1.19 \text{ SP} - 0.27 \text{ OP} \\ \text{FK}_2\text{O} &= 1.34 \text{ T} - 0.31 \text{ SK} - 0.56 \text{ OK} \end{aligned}$$

Vermicompost+ Azotobacter+ PSM

Pooled prediction equation of Rice:

$$\begin{aligned} \text{FN} &= 4.91 \text{ T} - 0.56 \text{ SN} - 1.21 \text{ ON} \\ \text{FP}_2\text{O}_5 &= 1.48 \text{ T} - 4.03 \text{ SP} - 0.47 \text{ OP} \\ \text{FK}_2\text{O} &= 1.58 \text{ T} - 0.49 \text{ SK} - 0.55 \text{ OK} \end{aligned}$$

Pooled prediction equation of Winter Maize:

$$\begin{aligned} \text{FN} &= 2.66 \text{ T} - 0.31 \text{ SN} - 0.67 \text{ ON} \\ \text{FP}_2\text{O}_5 &= 0.75 \text{ T} - 1.95 \text{ SP} - 0.34 \text{ OP} \\ \text{FK}_2\text{O} &= 1.39 \text{ T} - 0.40 \text{ SK} - 0.55 \text{ OK} \end{aligned}$$

Benefits of STCR approach

During the last more than four decades the STCR project has generated numerous fertilizer adjustment equations for achieving targeted yields of important crops on different soils in different agro ecological regions of the country. These fertilizer adjustment equations have been tested in follow up and frontline demonstrations conducted in different parts of the country. In these trials soil test based rates of fertilizer application helped to obtain higher response ratios and benefit: cost ratios over a wide range of agro-ecological regions (Dey, 2012, Dey 2015a; Dey and Srivastava, 2013). It is evident from above tables that STCR based approach of nutrient application has definite advantage in terms of increasing nutrient response ratio over general recommended dose of nutrient application. Yields and response ratios can be increased if the fertilizer prescriptions are made as per the table 1 for specified crops and locations.

Table 1: Average Response Ratios (kg grain/kg nutrients)

Crop	No. of trials	Farmer's practice	STCR- IPNS recommended practice
Rice	120	11.4	16.8
Wheat	150	10.3	14.2
Maize	35	12.7	17.7
Mustard	45	8.0	8.2
Raya	25	4.8	7.6
Soybean	17	9.6	12.2
Chickpea	35	6.1	9.4

Fertilizer recommendations for fixed cost of investment and allocation under resource constraints

The soil test-fertilizer requirement calibration for targeted yield also provide the means for calculating soil critical levels above which there is no fertilizer requirement indicated levels of expected crop production. A new dimension to the value of the utility of soil testing has been added by the concept of fertilizer application for targeted yield demonstration laid by IARI in farmers' fields by choosing the yield target at such a level so that the cost of fertilizer requirement becomes more or less same as what was being practiced by farmers already.

Extension of STCR technology through Front Line Demonstrations

More than five thousand frontline demonstrations have been organized by different centres of AICRP (STCR) our centres in farmers' fields of different states to demonstrate the developed STCR technology. Front Line Demonstrations conducted at farmers field clearly brought out the superiority of STCR-IPNS fertilizer recommendations for different crops over blanket recommendation and farmer's practice in terms of higher yields with higher BCR/net returns. Financial returns vary from soil to soil, crop to crop and location to location. An appraisal of the effect of nutrients (NPK) applied on crop yield and benefit: cost ratios (BCR), both under STCR without organic manure and under STCR-IPNS approach of nutrient recommendation (Dey and Santhi, 2014) for 15 agricultural and horticultural crops showed that out of 66 crop x target combinations, the BCR was between 1 and 2 in 35 % cases and between 2.1 and 3.0 in 62% cases. In 3% cases BCR was above 3. Irrespective of the crops, higher yield has been recorded at higher yield targets over lower target coupled with higher net return and BCR. Irrespective of the crops and yield targets, yield increase was higher with STCR-IPNS than under NPK applied through fertilizers alone.

Capacity Building under Tribal Sub Plan – A cornerstone in the STCR Process

Front Line Demonstrations conducted under Tribal Sub Plan (TSP) in Assam, Bihar, Chhattisgarh, Gujarat, Himachal Pradesh, Jammu & Kashmir, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Odisha, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh and West Bengal with tribal farmers' also clearly brought out the superiority of STCR-based fertilizer recommendation for different crops over blanket recommendation and farmer's practice and that even farmers with very little knowledge of modern agriculture could achieve yield target by practicing STCR technology within $\pm 10\%$ variations of the target set (Dey, 2015b; Dey, 2016).

Economic analysis of fertilizer doses associated with different yield targets

An appraisal of the effect of nutrients (NPK) applied on crop yield and benefit: cost ratios (BCR), both under (NPK) alone and under IPNS for 15 agricultural and horticultural crops (Dey and Santhi, 2014) showed that out of 66 crop x target combinations, the BCR was between 1 and 2 in 35 % cases and between 2.1 and 3.0 in 62% cases. In 3% cases BCR was above 3. Irrespective of the crops, higher yield has been recorded at higher yield targets over lower target coupled with higher net return and BCR. As in the case of yield, wherever three targets (low, medium and high) were tried, the BCR was relatively higher between low and medium target levels than between medium and high target levels both under NPK alone and IPNS. Again, irrespective of the crops and yield targets, yield increase was higher with IPNS than under NPK applied through fertilizers alone. In the regard, farmers can choose the desired yield targets according to their investment capabilities and availability of organic manures but would generally benefit from adopting an appropriate IPNS package as apart from contributing nutrients, organic manures also improve soil physical conditions. At present, the soil test based recommendations are relatively on a stronger footing when these involve only fertilizers as compared to IPNS. This is because there are several issues concerning the nutrient which need to be sorted out as illustrated using STCR information from Andhra Pradesh. One of the outstanding problems is that while the composition of fertilizers is fairly standard, that of organic manures can vary several-fold even within the same location or form lot to lot.

STCR vis-a-vis soil health

Fertilizer recommendation through targeted yield approach for maintenance of soil health

Fertilizer recommendation for realizing in the short term greater fertilizer use efficiency on the one hand and far maintenance of soil fertility in the long term and the other seem to have two opposing dimensions. If soil fertility is to be maintained or even increased, heavier doses of fertilizers have to be used to take into account the inevitable losses in the availability due to leaching and fixation. Therefore, to get the best out of fertilizer investment, the turnover from it must be very quick. This is ensured when fertilizers are applied far low yield targets. Under such situations, the excess native soil nutrient (S) will make a great contribution to increase the yield. This would mean low doses of application of fertilizer and exhausting of the unutilized excess nutrients from the soil. The soil fertility would, therefore, deplete at a

faster rate as a result of this exhaustion. Thus, these two approaches seem to be pulling in different directions and it will be necessary to adjust the fertilizer practices over seasons in such a way so as to strike a balance between the two.

The generation of basic data for targeted yield of crops in a rotation would enable application of fertilizer far appropriate yield targets so that over seasons, the twin objectives of high yields and maintenance of soil physical (Table 1) and biological (Table 2) could be achieved (Dey and Gulati, 2013). Singh et al. (2015b, 2017, 2018) also found beneficial effect of STCR based nutrient application on soil health in different cropping systems.

Table 1: Changes in bulk density, water retention and hydraulic conductivity of soil in guar- wheat cropping system under Rajasthan condition

Treatment	Soil depth (cm)	Bulk density		Water retention (%)						Hydraulic conductivity (cm/hr)	
		Y _i	Y ₃	Y _i (10 kPa)	Y ₃ (10 kPa)	Y _i (33 kPa)	Y ₃ (33 kPa)	Y _i (1500 kPa)	Y ₃ (1500 kPa)	Y _i	Y ₃
Control	0-15	1.52	1.53	8.80	8.77	5.60	5.58	1.90	1.88	10.4	10.51
	15-30	1.53	1.53	8.60	8.61	5.30	5.28	2.10	2.08	8.2	8.23
General recommendation dose (GRD)	0-15	1.52	1.52	8.80	2.82	5.60	5.63	1.90	2.11	10.4	10.32
	15-30	1.53	1.53	8.60	8.62	5.30	5.34	2.10	2.18	8.2	8.16
STCR	0-15	1.52	1.52	8.80	8.88	5.60	5.81	1.90	2.21	10.4	10.28
	15-30	1.53	1.53	8.60	8.69	5.30	5.42	2.10	2.36	8.2	8.11
STCR-IPNS	0-15	1.52	1.50	8.80	9.51	5.60	6.36	1.90	2.89	10.4	9.28
	15-30	1.53	1.50	8.60	9.22	5.30	6.07	2.10	2.51	8.2	7.76

Y_i: Initial; Y₃: After 3 years

Table 2: Changes in soil microbial biomass, dehydrogenase activity and organic carbon in guar-wheat cropping system under Rajasthan condition

Treatments	Soil depth (cm)	Microbial biomass (mg kg ⁻¹)		Dehydrogenase activity (P Kat/g)				Organic C (%)	
		Y _i	Y ₃	Y _i	Y ₃	Y _i	Y ₃	Y _i	Y ₃
Control	0-15	30 ±6.0	20 ± 3.2	1.05	1.06 ±0.06	0.11	0.07 ± 0.02		
GRD (without organics)	0-15	30 ±6.0	40 ± 5.4	1.05	2.10 ±0.07	0.11	0.10± 0.03		
STCR (without organics)	0-15	30 ±6.0	53 ± 5.5	1.05	2.88 ±0.07	0.11	0.12 ± 0.03		
STCR-IPNS	0-15	30 ±6.0	69 ± 6.3	1.05	3.93 ±0.07	0.11	0.19± 0.03		

Y_i: Initial; Y₃: After 3 years

Ecosystem services vis-à-vis STCR

From above discussion, one can easily see that STCR technology touches in all four broad categories of ecosystem services: provisioning, such as the production of food, fodder, fibres; regulating, such as the control of climate through carbon sequestration and improvement in soil health; supporting,

such as nutrient cycles; and cultural, such checking migration of tribal farmers by making agriculture as profitable venture in the remotest corners of the country and thereby providing time for cultural activities in the villages itself. Research works from plateau region also clearly demonstrate that indigenous people and their knowledge are central to the adaptive changes for sustainable agriculture using available natural resources essential to face the world's changing climate (Dey and Sarkar, 2011).

Decision support system for fertilizer recommendations

(<http://www.stcr.gov.in>)

All India Coordinated Research Project on Soil Test Crop Response (AICRP-STCR) based at Indian Institute of Soil Science has developed a computer aided model that calculates the amount of nutrients required for specific yield targets of crops based on farmers' soil fertility (Majumdar et al. 2014). It is accessible on Internet (<http://www.stcr.gov.in>). This software program reads data, performs calculations and generates graphical and tabular outputs as well as test reports. This system has the ability to input actual soil test values of the farmers' fields to obtain optimum dose of nutrients. The application is a user friendly tool. It will aid the farmer in arriving at an appropriate dose of fertilizer nutrient for specific crop yield for given soil test values (Fig. 1). Efforts are on way in developing bioinformatics, E-choupals, digital libraries and e Governance that can benefit agriculture immensely by way of providing information and assisting the users in adopting the newer technologies.



Fig.1. Internet enabled soil test based fertilizer application software

DSSIFER

Decision Support System for Integrated Fertiliser Recommendation (DSSIFER) is a user friendly software and the updated version (DSSIFER 2010) encompasses soil test and target based fertiliser recommendations through Integrated Plant Nutrition System developed by the AICRP-STCR, Department of Soil Science and Agricultural Chemistry, TNAU, and the recommendations developed by the State Department of Agriculture, Tamil Nadu. If both recommendations are not available for a particular soil – crop situation, the software can generate prescriptions using blanket recommendations but based on soil test values. Using this software, fertilizers doses can be prescribed for about 1645 situations and for 190 agricultural and horticultural crops along with fertilisation schedule. If site specific soil test values are not available, data base included in the software on village fertility indices of all the districts of Tamil Nadu will generate soil test based fertiliser recommendation. Besides, farmers' resource based fertilizer prescriptions can also be computed. Therefore, adoption of this technology will not only ensure site specific balanced fertilisation to achieve targeted yield of crops but also result in higher response ratio besides sustaining soil fertility. In addition, the software also provides technology for problem soil management and irrigation water quality appraisal. Moreover, STLs of all the organisations can generate and issue the analytical report and recommendations in the form of Soil Health Card (both in English & Tamil) which can be maintained by the farmers over long run.

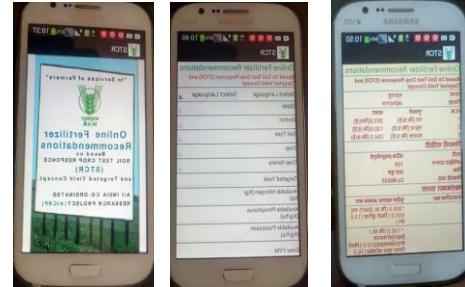
<http://www.soilhealth.dac.gov.in>

Recently the soil health card portal has been developed by Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Govt. of India for registration of soil samples, recording test results of soil samples and generation of Soil Health Card (SHC) along with

Fertilizer Recommendations through STCR prescription equations which is a single, generic, uniform, web based software accessed at the URL www.soilhealth.dac.gov.in. It is a workflow based application with following major modules: (i) Soil Samples Registration, (ii) Test Result Entry by Soil Testing Labs, (iii) Fertilizer Recommendations, (iv) Soil Health Card generation along with Fertilizer Recommendation and amendment suggestions, and (v) MIS module for monitoring progress. It promotes uniform adoptions of codes, e.g., Census Codes for locations. The system has sample tracking feature and will provide alerts to farmers about sample registration and generation of Soil Health Card through SMS and Email. Based on test results, these recommendations will be calculated automatically by the system. The System envisages building up a single national database on soil health for future use in research and planning.

STCR Mobile APP

Bilingual (Marathi and English) STCR Mobile App for fertiliser recommendations of Maharashtra was developed in collaboration with National Informatics Centre (NIC), Pune. Based on resource endowment capacity of the farmers, the App helps to realize the targeted yield of crops. Farmers can get the precise fertilizer recommendations based on soil test value and for a specific yield target. The STCR prescription equations for Sugarcane, Wheat, Upland Paddy, Transplanted paddy, Pearl millet, Kharif Sorghum, dryland rabi Sorghum, Finger millet, Fodder Maize, Bt Cotton, Groundnut, Soybean, Sunflower, Pigeon pea, Green gram, Chickpea, Okra, Brinjal, Cabbage, Cauliflower, Potato, Tomato, Turmeric, Chill, Onion, Garlic, Marigold, Bitter gourd, Banana, and Maize have been included in the APP.



New vistas of STCR

Of late, STCR has developed fertiliser prescription equation for hitherto untouched secondary nutrient (sulphur). Also developed algorithms of leaf colour chart, SPAD and fieldscout CM 1000 meter values at three critical growth stages with yield in rice-wheat system. Besides, soil testing protocol for organic farming system including characterization and quantification of microbiologically exploited organic phosphorus-pools in organic farming systems has been developed. STCR has also developed GPS/GIS-based soil fertility maps of 173 districts of India (Basavaraja et al., 2016, 2017; Chitteshwari et al., 2017, Maragatham et al., 2014; Mishra et al., 2015, 2016, 2017; Sellamuthu et al., 2015; Singh et al., 2015a, 2016). Such maps are being used for development of nutrient plans and also for soil quality assessment over a period of time by periodical assessment from same GPS sites for determining whether the soil is sustaining or aggregating or degrading.

Epilogue

Among the various methods of formulating fertilizer recommendation, the one based on STCR-IPNS which dovetails biofertilisers and organics, provides the choice to farming community about setting a realistic yield target based on available resources. This method not only indicates soil test based fertilizer dose but also the level of yield the farmer can hope to achieve if good crop husbandry is followed in raising the crop. It provides the scientific basis for balanced fertilization not only between the fertilizer nutrients themselves but also that with the soil available nutrients. Notwithstanding the uncertainty over Kyoto commitments and instruments, the twin aspect of devising strategies for leveraging resources to tackle the challenge of low carbon transformation and strategies to enhance soil health and carbon sequestration will help in combating climate change without compromising economic development. Positive incentives for private investment for promoting soil carbon sequestration is also necessary. Moreover, region-specific amalgamated technological prescriptions refined with targeted policy analysis are required for effective implementation and obtaining positive outcomes within a finite time horizon. This will provide a strong foundation for pragmatic policy formulation on natural resource conservation and combating climate change.

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Soil test based Integrated Nutrient Management (INM) in farmers' fields based on Participatory Diagnosis of Constraints and Opportunities (PDCO) survey: Indian experience

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The Management of soil and plant nutrients should be addressed as an integral part of overall soil productivity and in the context of an economically justifiable, socially acceptable and environmentally sound production system of the farm household (FAO 2000). The productivity of a soil depends on its fertility and thus on its physical, chemical and biological characteristics. For efficient management of soil and plant nutrients, an integrated approach to plant nutrition must be adopted. This is achieved through conservation and the efficient use of on-farm sources of nutrients (e.g. soil reserves, crop residues and animal wastes), through the judicious importation of nutrients from off-farm sources and through facilitating nutrient generation on the farm itself by natural processes such as nitrogen fixation. The main underlying principle is to mobilize all available, accessible and affordable plant nutrient sources as investment assets, in order to optimize the productivity of cropping systems and their profitability to the farmer. It is now well established that any sustainable soil productivity improvement programme should follow a participatory approach with the farmers in understanding their problems and addressing them.

For this purpose, the following steps are foreseen:

- Selection of intervention areas based on agro-ecological zones/subzones, using existing information.
- In each identified agro-ecological zone, identification of villages or communities representative of different cropping/farming systems, socio-economic conditions, dominant soil/nutrient management practices, etc. through rapid rural appraisal (RRA) and analysis of available basic information.
- In each identified community, participatory diagnosis of constraints and opportunities (PDCO) related to soil and plant nutrient management. This should result in an overall assessment of the local diversity, a classification of major categories of farmers, and assessment of current management practices related to natural resources (including soil and water conservation), communal areas (forest and grazing lands), use and availability of external resources, constraints in improving soil/crop productivity; and potentials (agronomic, and family food demand and market/economic opportunity) for improving the productivity. An apparent (estimated) plant nutrient balance sheet for the community should also be attempted for a global understanding of the soil fertility situation.
- An in-depth assessment for one or two representative farms within each identified farm category. This diagnosis jointly with the farmer should assess his/her production, present management practices (soil and nutrient), constraints, a farm nutrient balance, technological opportunities that can be immediately adopted for improving productivity, and identification of potential options that

are applied elsewhere but not tested under the present condition. This analysis should lead to a soil productivity improvement programme, including group demonstration, testing technologies with the farmers and adaptive trials to be conducted jointly by farmers and scientists.

As an activity in this direction, a FAO-ICAR-IFFCO collaborative project was executed with ICAR-IISS, Bhopal as coordinating centres. For this project the FAO had funded and provided technical backstopping. Indian Farmers' Fertilizer Cooperative Organization (IFFCO – a govt. of India Undertaking) has worked primarily as the lead agency in undertaking developmental activities in the "satellite villages" and Indian Council of Agricultural research (ICAR) has executed the technical, research-oriented components, formulation and implementation of the technical programme in the "core village", overall leadership, coordination, monitoring (with IFFCO) and report writing. To characterize and quantify various plant nutrient sources. The objectives were:

- To make practical recommendation on nutrient application based on IPNS for testing and extension
- To generate data on the field applicability of IPNS approach and to subject it on agro-economic analysis
- To refine the IPNS based recommendations for extension and transferring to similar areas elsewhere in the country
- To construct nutrient balance sheets to evaluate the performance of different technologies from the point of view of sustaining high yields and soil fertility maintenance.

As a part of the project, the technical and field activities were based in the following agro-eco-regions:

Region	System studied	Villages selected	
		Core	Satellite
Agro-eco region 4.1 Hot semi-arid with alluvial soils	Rice-Wheat	1	1
Agro-eco region 10.1 Hot sub-humid with red-black soils	Soybean-wheat	1	1
Agro-eco region 12.2 Hot sub-humid with red and laterite soils	Rice-based	1	1

However, the activities were also extended to the cooperating centres of All India Coordinated Research Project on Soil Test Crop Response representing other agro-ecoregions.

The key aspects of the methodology included

- Quantification of available nutrients from various sources
- Quantification of the potential and practical contribution from available nutrient supplies taking into consideration their competing uses
- Quantification of nutrient removal by different cropping systems
- Development of integrated nutrient recommendations
- The methodology will include liming as a component of IPNS in all acid soils
- The methodology will integrate chemical analysis, field experiments and refinement of nutrient recommendations involving the farmers not only in conducting the field trials but also in their experience in utilizing various sources of plant nutrients

Participatory Diagnosis of Constraints and Opportunities (PDCO)

In this approach, joint analysis of the agroecosystem is focused on the assessment of variety of issues, including farming systems, changing inputs and outputs at farm level; analysis of differences in soil management practices by wealth, age and gender; and influence of external economic and political

factors. This phase of the work was done by using a variety of participatory rural appraisal methods, as well as more conventional historical and anthropological approaches. Each contributed to an overall assessment of the area, discussed at each stage with the village participants. Once different socio-economic, gender and age categories of farmers had analyzed their bioresource flows, a number of problems were defined. These may be more generally felt by the farmers or they may be specific to a particular farm. Potential solutions were then sought through searching of alternative intervention options. With a range of alternative options to test, farmers and researchers then designed an experimental and monitoring programme together. Training workshops on IPNS were arranged at Indian Institute of Soil Science, Bhopal to train the researchers in conducting the PDCO.

Treatments for field experiments

The following treatments were suggested based on previous knowledge, recommendations and PDCO experience.

- Treatment 1: Farmers' Practice
- Treatment 2: Soil test based fertilizer dose for a high yield target (But not the highest target)
- Treatment 3: Soil test based nutrient dose based on IPNS (Existing technology)
- Treatment 4: IPNS approach (resource combination based on PDCO)

In these trials, the residual effect of the nutrients applied to crop 1 in the system was studied on crop 2 of the system along-with the direct effect by splitting the plots. Following observations were taken

- Yield data from each plot
- Crop sample analysis to assess nutrient removal
- Economic analysis of the yield data using prevailing input and output prices and other cost and benefits
- Computation of nutrient balance sheets

Results of PDCO trials carried out at different locations in India

Agro-ecoregion 10.1 at Bhopal	Organic manures like farmyard manure, goat manure and compost are applied once in 4-5 years based on their availability. Considerable differences were found in the actual and potential availability of N, P and K from organic resources. This is because only 30% of the cow-dung goes into the pits for production of FYM and the rest is used as dung-cakes. Also there was considerable nutrient loss in the FYM pits. Results of the field trials showed that in soybean-wheat system balanced fertilization based on soil tests with 4 t/ha of FYM to soybean crop was the best in terms of system productivity.
Agro-ecoregion 4.1 at Meerut	The survey conducted to assess the prevalent IPNS practices in the adopted villages revealed that use of different IPNS ingredients varied among the holding-size categories of farmers. Farmyard manure (FYM), sulphitation pressmud (SPM) and rice crop-residues are the major organic inputs used to meet the nutrient demands of rice and wheat. Soil-test based IPNS, involving 5 t ha ⁻¹ SPM at one site and 4 t ha ⁻¹ FYM at the other, gave the highest grain yields of rice, which were greater than the fixed targets by 0.22 t ha ⁻¹ at SPM site and by 0.12 t ha ⁻¹ at FYM site. In demonstrations plots also soil-test based IPNS was superior to farmers' practice (FP), and the extent of yield increase due to use of SPM and FYM over FP was 0.64 and 0.65 t ha ⁻¹ .
Agro-ecoregion 12.2 at Bhubaneswar	Only farmyard manure is prepared and used on the farms in rice-based systems. The quantity of farmyard manure produced on a farm varied from 2 to 20 tonnes. Rice straw is used as cattle feed and not recycled on the farm. The amount of manure applied varied from 2 to 5 t/ha. The targeted yield with application of FYM alongwith inorganic fertilizers was proved to be superior to the targeted yield with application of only inorganic fertilizers.

District Hisar, Haryana	Farmers generally use FYM @ 7.5 t/ha in alternate years. Some farmers also apply poultry manure. Farmers use <i>Rhizobium</i> culture for legume crops. Bajra-wheat, bajra-gram, bajra-mustard, cotton-wheat and rice-wheat are the principal cropping systems followed. Field trials were laid out with rice-wheat cropping system. The yield targets of 70 q/ha in TY -70 (7.5 t FYM) and TY-70 (15 t FYM) treatments were achieved within -6.5 to + 2.6 per cent deviation. These results indicated the yield targets could well be achieved even if we deduct nutrients supplied by FYM from the chemical fertilizers.
Ropar district, Punjab	Farmyard manure is generally used in sugarcane crop. Green manuring is not successful due to borer attack. Rice stubbles are incorporated into the soil, however, mechanically threshed crop is burnt, as incorporation is a real problem. Wheat straw is removed from the field and used as cattle-feed or sold in the market. Though many farmers are aware of the benefit of integrated nutrient management, yet the practice is not commonly followed.
Samastipur district, Bihar	The yield data and economics of cultivation of both rice and wheat revealed that balanced use of chemical fertilizers with additional FYM @ 5 t/ha is the best treatment. However, under limited and restricted availability of organics, use of compost @ 2.5 t/ha with or without BGA @ 11 kg/ha alongwith the substituted chemical fertilizers may be a viable option.
Durg district, Chhattisgarh	The major portion of cow-dung is used for making dung cakes by small farmers. However, other category farmers use cowdung for preparing FYM. As a result the FYM from medium and resourceful farmers has greater concentration of nutrients (N + P ₂ O ₅) than the FYM from poor resource farmers. The fertility statue of soil also matches with their fertilization and manuring practices, being higher in resourceful farmers category. Different organic input options (FYM @ 5t/ha, FYM @ 3t/ha + BGA @ 10 kg/ha and green manure), identified through PDCO, were tried alongwith comparable dose of chemical fertilizers for rice. Yield targets were fixed based on farmers' resource and his capacity to invest. Chemical fertilizers with 5t/ha FYM was found the best treatment for rice under poor and medium resource farmers' categories. Considerable saving in the N and P fertilizers could be made with almost similar productivity of rice-wheat in chemical fertilizer alone and IPNS system with FYM as component.
Ahmednagar district, Maharashtra	Fertilization of wheat for 35 q/ha target (20% reduced dose than actual requirement) with FYM @2 t/ha and <i>Azotobacter</i> was the best available options for wheat with highest grain yield and monetary return. STCR recommendation for 12 q/ha target (20% reduced dose) + 5t FYM/ha with <i>Azotobacter</i> was the best option for sunflower.
Bangalore rural district, Karnataka	The highest paddy grain yield of 81.8 q/ha was obtained in the treatment full inorganic as per STCR followed by treatment 75% inorganic + 25% organic (4t FYM/ha) (74.2 q/ha) and treatment 50% inorganic + 50% organic (8t FYM/ha) (74.8 q/ha). All these yields were, however, much higher than the yields obtained in general recommended dose (GRD) and farmers' practice. Similar trend in crop yields were also observed for ragi crop. IPNS treatments yielded less since the crops were stressed for nutrients.
Nellore district, Andhra Pradesh	Farmers use FYM, green manure and poultry manure as organic sources of plant nutrients. Small farmers use FYM every year but medium farmers use in alternate years. Large farmers generally do not use FYM. The farmers of this village incorporate paddy straw left after combine harvest into the soil. 'Sunnhemp' crop can be used as green manure during kharif season. The results of both sunnhemp (5t/ha) and FYM (10t/ha) alongwith appropriate doses of chemical fertilizers can give significantly higher yield of rice with considerable saving in N and K fertilizers.

Thondamuthur <i>Panchayat</i> and Udumalpet <i>taluk</i> , Tamil Nadu	Thondamuthur panchayat represents irrigated as well as, rainfed agriculture. The commonly cultivated crops are rice, groundnut, tapioca and maize. Farmyard manure and biofertilizers such as Azospirillum and rhizobium were found as viable options under IPNS. In Udumalpet taluk the dominant cropping sequence is rice-rice-pulse/oilseed. In this taluk green leaf manure such as <i>Calotropis</i> and <i>Kolengi</i> are available with farmers for integration in the IPNS technology. If farmers make use of organic manures available from their holdings and follow soil test based balanced fertilizer recommendation, there would be saving of fertilizer nutrients and increase in net profit.
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Harnessing ICT for Precision nutrient management: A viable option to bring resilience to climate change for small-holding farmers of South Asia

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Introduction

Agriculture is the main occupation of food production and sustenance for the inhabitants of the south Asia. During 20th century synthetic fertilizer was introduced and enhanced the crop production in the region. Simultaneously the population of these nations increased geometrically caused excessive use of synthetic fertilizers in want of better production but that resulted enhanced yield for few decades and later either stagnation or declining crop production and even affecting soil quality/health and ultimately food security. The current work has emphasized on soil and crop management for ensuring good soil quality. Soil quality/health can be managed through addition of balanced synthetic fertilizer, integration of organic sources and proper agronomic management practices. The studies have put forth the constraints in managing balanced use of fertilizer are the lack of information/awareness prevailing with agrarians, ill equipped soil testing laboratory, and neglecting of use of organic manures. In order to ensure food security and soil management precision nutrient management can play an important viable options.

The advent of precision nutrient management concept that occurred in the western countries decades ago used the application of advanced and innovative technologies for the benefits it provides in relation to time management, efficiency, economics, and natural resources conservation. The majority of the farmers' community of south Asia have small land holdings due to over encumbrance of population. Application of precision nutrient management that has been introduced recently may accelerate the crop production, protection from climate change impact as well as soil quality management in the region. Because of limited resources and the scarcity of trained technical, scientific and extension personnel, there is currently an inability to provide farmers with timely up-to-date advice. Application of ICT with precision nutrient management would greatly facilitate the rapid exchange of information about a viable option to bring resilience to climate change and provide a platform for communication and capacity-building for small holding farmers of south Asia.

Precision nutrient management

Precision nutrient management stand on five "R" concept. In 1994, Robert and his co-worker proposed three "R"s, the Right time, the Right amount and the Right place. Later the IPNI (International Plant Nutrition Institute) added another "R" to the above list, "the Right Source" called as four "R" stewardship concept, and recently in 2008, Khosla added an additional "R", the Right manner. These five "R" is of great importance for global precision agricultural practices.

Current crop production system is majorly attributed by the use of synthetic commercial fertilizers. To feed overgrowing population in changing climatic aberrations with the limited land area, limited nutrient status, limited water resources, and scarce labour availability in the forthcoming decades with sustainable approach will be challenging and hence to achieve the HGGs (human generated goals) of food production without compromising the natural resources on which agriculture depends the required resources including nutrients have to be used in a precise manner. The precision nutrient approach for smallholding farmers in south Asia operating their farming activities under wide range of soil type, variable moisture conditions and various socioeconomic conditions is really a boon and generate profitable production

system. The efficacy and sustainability of the system entirely based on interactions between these limited factors. The precision approach closes the yield gap and maintain farm profitability in the system.

Use of ICT for precision nutrient management

The data science and spatial data availability present in the institutional system can characterise the soil, crop and environment rapidly and cost-effectively and with greater precision scale. Such information is being used to develop ICT based tools for precision nutrient management as well as in-season adaptive management at an affordable scale. We are aware that the existing approaches either using soil testing approach or Soil test crop response (STCR) approach have proven too costly or difficult to extend to large farming community. Future gains in productivity and input-use efficiency will require technologies that can manage soil, water, and crop and are more knowledge-intensive and tailored to the specific characteristics of individual farms and fields. Precision nutrient management approach manages the soil variation, nutrient status and crop responses. The concept for optimizing the supply and demand of nutrients according to their variation in time and space. However, for scaling such approach ICT tool can eventually as a web- and mobile phone based application/software can precisely provide field specific nutrient management detail in the form of recommendation to the smallholding farmers in the south Asia. The ICT based tool is being tailored to specific local conditions. The developed tool is simple, user-friendly interface providing personalized fertilizer guidance for small-scale farmers, and extension workers. Rice Crop Manager (RCM) is a web based browser app works on the concept of site specific nutrient management (SSNM) and provide precise crop and nutrient management (Figure 1) to the smallholding farmers in South Asia.

Precision nutrient management resilient to climate change

Climate change under current scenario is at stake due to excessive/injudicious application of commercial synthetic fertilizers. Knowingly or unknowingly agrarians of these regions dump the overdose

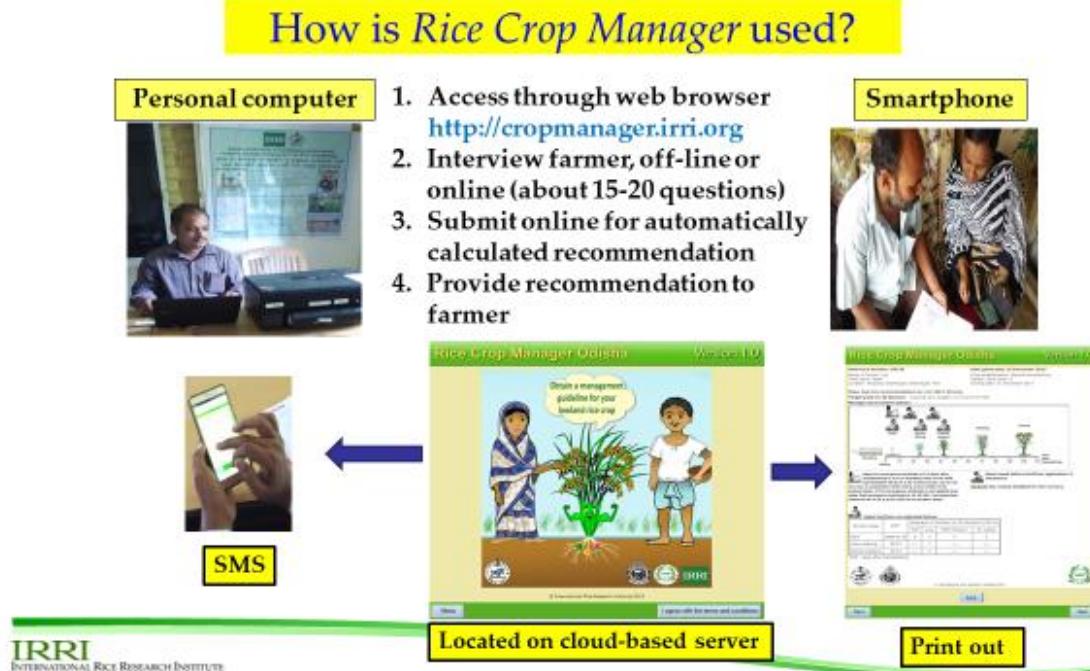


Figure 1: SSNM based Rice Crop Manager

of inorganic fertilizers in want of increasing food production for their sustenance. How soil, water, crop, and climate got affected is least bother by them. Use of ICT tool based precision nutrient management has paved the new era of fertilizer management that can take care of farmer's production demands and

also bring resilient to climate change. Precise nutrient application limits optimises the inorganic fertilizer nutrient doses and save the climate from the ill-effects of aberrant conditions. A demo study on the use of SSNM based Rice Crop Manager (RCM) in farmer's field at Odisha has shown yield enhancement of approximately 1 t/ha and also saving of half dose of phosphorus and potassium as when compared with yield and fertilizer application done based on farmer fertilizer practice. Noting the information obtained from previous study has represented the saving of fertilizers and thus protecting the environment from its ill effects. This study and its impact can provide such information that will really help to change the mind-set of the farmers of the south Asia and create awareness about safeguarding the environment in which they live in. Therefore, precision nutrient management can be a source to protect climate and make this earth for better living place.

Conclusion

Under current situation precision nutrient management can be a better approach not only to meet the food challenges and socioeconomic condition of small holding farmers of South Asia but also can be a viable option to bring resilience to climate change. Creation of awareness on this direction will definitely help to save earth and save environment.

Integrated Plant Nutrient Supply System – A conceptual framework

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In literature at least three terminologies are being used, often to convey the same meaning – Integrated Plant Nutrition Systems (IPNS), Integrated Plant Nutrient Supply System (IPNS system and Integrated Nutrient Management (INM). Although these three terminologies may look the same superficially, yet they are essentially not the same and they convey somewhat different connotations (Goswami, 1997).

While “IPNS system” means the supply of nutrients to the plant from various sources of nutrients (i) nutrient reserves in the soil (ii) organic sources – FYM, compost, green manure, crop residue and other organic fertilizers; “IPNS” is a concept “Which aims at the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of benefit from all possible sources of plant nutrients in an integrated manner” (Roy and Ange, 1991). Thus, “IPNS system” is only a method to achieve the objective of “IPNS”. In the latter is embedded a philosophy with social, economic and technological components while the former provides a strategy to achieve the said objective.

Integrated nutrient management (INM) is actually the technical and managerial component of achieving the objective of IPNS under farm situations. It takes into account all factors of soil and crop management including management of all other inputs such as water, agrochemicals, etc., besides nutrients.

IPNS is basically an open system with soil, plant, animal and the immediate environment as components of the system and nutrients from various sources so supply, as flow to the system (both inflow and outflow). The nutrient flows in the system, soil >> plant >> animal >> soil are determined by soil parameters, plant requirements, the crop residues, roots and stubbles remaining in the soil, the animal dung/excreta put back to the soil, and therefore the rate and volume of flows in the various components of the system would vary. IPNS takes into account a quantity aspect, an intensity parameter and a supply power parameter. Properly put to use the system should be able to supply and regulate the flows and volumes of nutrients in the systems. Integrated use is not the same thing as complementary use. It is not A+B (A, B being two sources) but something much more, particularly when talking about a complex system such as soil and plant, both being living entities.

According to Ange (1997), a simplified model of IPNS uses five major concepts (should be criteria not concepts in my opinion), (a) immobilized capital of plant nutrients, (b) working capital of plant nutrients, (c) annual investments in plant nutrients (d) plant nutrients losses (e) plant nutrient outputs. Plant nutrients stored in the soil are immobilized in that they should not be exhausted/depleted under a given level, and also in that the rapid transfer of those nutrients is not possible. Plant nutrient in crop residues, manures, green manures and domestic wastes compose the “working capital” of plant nutrient because farmers can transfer and allocate those nutrient sources to a particular crop in a crop rotation. All plant nutrients purchased or obtained from outside the farm premises compose the annual investment. The plant nutrient output of the system results from the plant nutrient uptake at harvest time. IPNS aims at an immediate improvement of the efficiency and profitability of the plant nutrient practices and at the same time building up of the production capacity through an improvement of the immobilized capital, to the working capital, of the investments and a reduction of plant nutrients losses

Thus, IPNS aims at efficient and judicious use of all the major sources of plant nutrients –soil, fertilizer, organic and biological in an integrated manner so as to maximize economic yields for a given cropping system and at the same time maintaining/improving soil productivity. The main objective is to efficiently utilize all the sources of plant nutrients.

Relevance and importance of IPNS

The importance of IPNS approach is clearly borne out from the results emanated from the Long Term Fertilizer Experiments (LTFE) of the ICAR. In fact, the very essence of IPNS is inherent in the objectives of the LTFE which was started in a systematic manner covering major agro-ecological zones and soils of the country in 1970. The basic objectives of LTFE are to develop strategies and policies for rational fertilizer use management and in improving the quality of soil and environment, i.e. productivity, sustainability and environment safety. The Long Term Fertilizer Experiments have very clearly made us learn lessons which would go a long way to popularize integrated plant nutrition approach. The important lessons from the LTFE are:

- Continuous use of N along produced greatest decline in yield and had deleterious effect on long term fertility and sustainability, indicating that other major and micronutrients were becoming limiting factors and adequate response to N could not be obtained unless those factors limiting yield were taken care of.
- Up to a number of years, the responses to NPK+FYM were not distinctly different from NPK alone, but after some years, responses to NPK alone were lower than that to NPK + FYM. This indicates that with time intensive agriculture relying mainly on NPK would accentuate deficiencies of secondary nutrients such as S and micronutrients, mainly Zn.
- The effects of FYM was more conspicuous in maize, perhaps because it improved the physical condition of the soil, besides supplying additional nutrients such as S and Zn.
- The effect of NPK + FYM was comparable or often superior to that of NPK + lime in acid soils, indicating that to a certain extent the benefits of liming were met by the FYM which also has buffering effect on soil acidity correction. The latter observation was corroborated by the changes in pH in those soils.
- FYM application is absolutely essential in light textured soils (red sandy, laterite) and soils with problems of acidity.
- FYM has manifold effects – on some soils its beneficial effect on improved physical condition of the soil is more manifested, on some its nutrient supply effect (mainly secondary and micronutrients), and on still other s its effect as a source of organic carbon is manifested.

WHY IPNS? What is expected of it?

IPNS should serve four major functions:

- It should adequately take care of plants nutritional needs for optimum biological productivity and economic gains to the farmer through the products of use.
- It must adequately ensure that in the process, the soil the anchorage and medium on which plant is grown, is not impoverished and/or degraded
- It should be relevant to the diversity of environment, soil and cropping systems
- It should be relevant to the local situations, social, geographical, economic situations and farm/farmer specific.

For the above, IPNS must take into account

- Availability of other inputs such as water which affects nutrient availability and supply in the soil.
- Physical, chemical and other constraints in the soil
- Availability and supply of plant nutrient sources, in terms of quantity, cost and time,
- Nutrients needs of crops/cropping systems
- Climate
- Farmers' own resources and management capability.

IPNS encompasses a larger canvas to include soil, plant, animal and the immediate environment with the farm and the farmer as the focus. Since all materials, be it fertilizers, manures, crop residues etc., would find their way to the soil in and through which the nutrients would ultimately play and interplay their roles in plant nutrients, the soil holds the key to all reactions and interactions in the process. Therefore, in the ultimate analysis, the soil quality and its productivity would determine whether the IPNS is relevant, effective and successful.

Soil – its functions vis-à-vis IPNS

Soil is a renewable resource and is constantly undergoing modification in relation to life in general, the soil exhibits three main clusters of functions viz., (a) biological functions (b) nutritional functions, and (c) exchange and filtering functions

The soil shelters numerous animals and plant species. Serial biological cycles pass through the soil and/or incorporate the soil which is thus integrated into numerous ecosystems. The biological diversity of the earth's species may be closely linked to the pedosphere.

The biological activity of the soil is, moreover, essential for its formation, development, structure and fertility. Soil does not and cannot exist without abundant and diversified biological activity.

Soil produces and contains all the substances essential for life. It accumulates, then releases, the bulk of these elements to plants and animals. Soil acts as a storehouse, the size and capacity of which arises according to the situation. A large part of what plants eat, drink and breathe comes from the soil. So, the soil must be preserved for its nutritional and biological functions.

The soil is a porous milieu; it is constantly traversed by flows of water and gas, flows which exchange their mineral and organic components with those of the soil, through the unique functions of exchange and filtering by the latter.

IPNS vis-à-vis intensive/modern agriculture

Traditional agriculture which has perpetuated itself by allowing societies to develop, is agriculture that understates how to conserve soils and their fertility or how to create them. This agriculture was diversified, according to the type of environment – soil, climate and other ecological features. In contrast, modern agriculture disregards the diversity of environment, soil and crop species. It reduces soil to a narrow notion of material which it is certainly not.

There is a danger that this agriculture may weaken and destroy soils, marginalize and expel farmers. Soil deterioration occurs when the biological and physico-chemical properties of the soil no longer have time to renew themselves naturally or are not renewed artificially.

The IPNS must check soil deterioration, biological impoverishment and reduction in levels of organic matter through such measures as adding manures and composts, green manuring, crop rotation including legumes, and associating plants with different root systems. Maintenance of an "organic minimum" is essential. This minimum could vary for diverse soil and environmental studies and cropping systems.

IPNS and Balanced fertilization

Conceptually balanced fertilization would essentially mean rational use of fertilizers and organic manures for supply of nutrients for agricultural production in such a manner that would ensure (1) efficiency of fertilizers use, (ii) harnessing best possible positive and synergistic interaction amongst the various other factors of production (seed, water, agrochemicals, etc), (ii) least adverse effect on environment by minimizing nutrient losses (iv) maintaining soil productivity and (v) sustaining high yield commensurate with the biological potential of the crop variety under the unique soil, climate and agro ecological set up. Balanced fertilization must be based on the concept of integrated nutrient management for a cropping system as this is the only viable strategy advocating accelerated and enhanced use of fertilizers with matching adoptions of organic manures and biofertilizers so that productivity is maintained for a sustainable agriculture. The balance has to be made in the soil crop system over time and has to take care of all other factors of production and make allowances for residual effects of past fertilizer applications, biological N fixation. Etc., and to ensure that there is no toxicity/deficiency of any element (Goswami 1997). The above concept of balanced fertilizer is almost synonymous with that of IPNS.

Agenda for Action

IPNS as well as balanced fertilization are conceptually the same and are intended for five major goals to be achieved. These are (i) to maintain soil productivity (ii) to ensure a productive and sustainable agriculture (iii) to prevent degradation of the environment, (iv) to reduce expenditure on costs of purchased inputs by using crop residues, animal dung available at the farm/farmers' premises and (iv) to meet the social and economic aspirations of the farmer.

To achieve the above objectives, the strategies are

- Increase the use efficiency of fertilizers by (i) reducing losses of nutrients from the soil-crop system (ii) using soil test based fertilizer recommendation in optimum and balanced amount for the cropping system as a whole, (iii) using fertilizer through most optimum modes, methods and techniques and (iv) using most efficient soil, water and crop management practices.
- Attempt to bridge the gap between nutrient removals through harvests and nutrient addition to reduce soil mining (LTTE results have clearly shows the exploitation of K reserves from the soil even at 100% NPK treatment).
- Integrated use of all sources of nutrients as per soil and crop needs (For examples, maize needs a better soil physical condition and red acid sandy soils do not respond to NPK unless FYM/lime is applied).
- Use crop rotation involving legumes
- Apply the available organic sources of nutrients which are in short supply to only those soils and crops which benefit most from such addition.
- Use land capability and use information from NBSS and LUP for determining most suitable cropping pattern, and use cropping sequences with crops of different rooting patterns.
- Encourage farmers to practice organic recycling.
- Remove deficiencies of nutrients as and when first detected and ameliorate problem soils with appropriate amendments.

Suggested Action Plan

- Educate the farmers through the media, mass contact and awareness programmes and on-farm demonstrations the important of IPNS.
- Encourage farmers to invariably get soils evaluated for quality, fertility and overall productivity.
- Establish single window system of delivery and information dissemination for fertilizer recommendations based on soil test need supply of bioinoculants, biofertilizers, legume seed for green manuring, and information on compost making techniques. Such centers are to be established at Soil Testing Laboratories, KVK's and Block/Panchayat levels

- Educate the farmer about soil- its nature and importance for mankind, and the need to preserve it for posterity.
- Advise the farmer to incorporate crop residue into the soil or to retain on surface to the extent possible.
- Advocate use of diversified cropping system, suitable crop rotation and mixed farming.
- Educate the farmer about the principles for sound water and nutrient management as an over all strategy for soil and crop management.
- KVKSs, fertilizer industry and NGOs should be motivated to propagate the usefulness of IPNS through a participatory approach.

Integrated Plant Nutrient Supply System for improving soil quality

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The use of chemical fertilizer and irrigation commonly known as conventional technology, grew exponentially to reap the potential benefit of the green revolution and we must recognize that Integrated Plant Nutrient Supply (IPNS) system is not meant to replace the conventional technology. It is a step in the direction of sustainable production through the necessary modifications of the conventional technologies and to ensure favorable soil health. The entire agro-production tract of the world is congenial for the adoption of IPNS technologies and what is needed to the most is to convince the farmers through demonstration of comparative economic efficiency of IPNS system over time for accepting the implicit hypothesis that IPNS is a more sustainable practice than conventional practice. Soil organic Carbon (SOC; concentration and pool) and its dynamics are key determinants of soil quality (soil health) and for the provisioning of essential ecosystem services. The primary control of soil quality vis a vis organic carbon distribution is rainfall and/or irrigation which supports increased production of above ground vegetation, resulting in increased allocation of carbon to the soil through greater root biomass and associated carbon inputs by root exudates and increased plant residue returned to the soil. Suitable management practices to build up SOC are those that increase the input of organic matter to the soil and decrease the rate of SOM decomposition (FAO 2011). The magnitude and rate of SOC sequestration that may be achieved depends on several factors, including the reference SOC stock (for a given soil), extent of adoption of IPNS system, cropping intensity, soil type and soil and water conservation practices.

Conceptual frame work of IPNS

Integrated plant nutrient supply (IPNS) system is a “system approach” to farming and involved management strategies of meeting nutritional requirements of the crops/cropping systems which is/are economically viable in short run and ecologically sustainable in long run. As it is a management system, it has four distinct integral components and strategic approach to harvest the benefits of each of the four components in totality would determine the success of the IPNS system.

On site nutrient resource generation

Under this component, mainly additional amount of nutrient N and organic C can be incorporated and added to the soil. Returning the crops residue to the soil also onsets the process of recycling of nutrients and thereby minimizes the gap between nutrient removal and nutrient addition in a production system. Most residues need some type of physical processing or shredding to facilitate their rapid decomposition in the soil. Nitrogen depleted crop residues (having wider C:N ratios) such as residues of cereals and other non-leguminous plants are known to temporarily immobilize soluble soil N and thus create a shortage of plant available N. If such residues are incorporated 3-4 weeks before the crop is sown, the N immobilization effect can be reduced (Toor and Beri, 1991). With mechanization of agriculture, considerable area under rice and wheat is now harvested with combine and the left over residues are available for onsite incorporation into the soil. Sidhu and Beri (1989) reported that in situ recycling of crop residue in a rice and wheat rotation reduced grain yield of both the crops. Burning the residue causes loss of precious organic matter, plant nutrients and environmental pollution. Experiments conducted in Punjab have shown that co-incorporation of green manure and crop residues of wheat and rice helped alleviate the adverse effect of un burnt crop residues on crop yields.

Green manuring can be made as an integral part of the production system, particularly where double crops are raised in year. In rice-wheat and maize-rice rotation, about 60-70 days lag period is

available after the harvest of wheat and before the transplanting of rice or sowing of maize. Short duration dual purpose grain legumes like mungbean/cowpea or typical green manure crops like dhaincha/sunnhemp can be grown.

For efficient on-site nutrient resource generation, following strategies need to be emphasized.

- Development of fast growing high N-fixing green manuring crop varieties to match the diverse climatic and soil crop situations and needs to be undertaken.
- Identification of lag period of the cropping systems practiced in a given area and preparation of data base for various options of practicing green manuring.
- All the crop residues other than those used for animal feed, should be returned back to the soil to onset the process of recycling. Burning of residues should be banned through legislation.
- For woody crop residues of pigeon-pea, cotton, etc. efficient technologies should be evolved to enhance its faster decomposition in soil through the process of chemical hydrolysis.
- Large scale extension education is required to popularize green manure and residue management technologies.
- Encouragement and strong government support for adoption of green manure.

Mobilization of off-site nutrient resources

Mobilization of various off-site nutrient resources is an important component of IPNS system. Potential availability of various non-fertilizer resources of plant nutrients like crop residues, livestock dungs, farmyard manures, composts, agro-industrial wastes and well pulverized mineral ores(Phosphate rocks, gluconites, pyrites etc)have to be estimated and information on the availability in local and regional perspective should be documented. For agriculture production, there cannot be better technology of using non-renewable sources of energy than utilization of inexhaustible atmospheric dinitrogen through biological nitrogen fixation (BNF).

The use of asymbiotic bacteria like *Autobacter* and *Azospirillum* has not become a common practice because of competition under natural soil condition. In general, *Azospirillum* is more appropriate for cereals and *Azotobacter* for non-foodgrain crops such as sugarcane, potatoes, cotton and vegetables. In terms of potential, *Azospirillum* is second only to blue green Algae (BGA).Blue green Algae are mainly used for rice. However, the application of improved strains of BGA inoculants has not made much head way due to dependence on rains, low availability of P and Fe in soils and its susceptibility to grazing by invertebrates that flourish in rice fields. *Azolla*, is also a potential BNF system for wetland rice and is as efficient as BGA. However, BGA is more efficient in conjunction with higher amount of mineral fertilizers. *Azolla* grows well in neutral soils with high availability of P and Fe with temperature range of 25-30C of the standing water. It can fix up to 30 kg N ha^{-1} month $^{-1}$.The other bio-fertilizers containing phosphate solubilizing micro-organisms can be used successfully to increase the mobility of native P and insoluble P applied through non-industrial grade rock-phosphate. Among the Mycorrhizas, Vesicular Arbuscular Mycorrhizas (VAM) is most promising in P cycling and enhancing P uptake by plants. It is especially suitable for transplanted, nursery and plantation crops. Among the mineral resources, synthetic and mineral fertilizers are the major source of nutrient supply to meet the nutrient requirement of the crops. It is very much pertinent to introduce the IPNS system for long term management of soil fertility and harnessing the maximum benefits from the chemical fertilizers.

Direct use of Low grade rock phosphate is also an important preposition to supply P at low cost through IPNS system. The other mineral deposits or wastes like gluconite/mica-waste, fly ash/flue dust, etc. can also be mobilized through IPNS system to meet the requirement of K,S, etc. (Rao et al., 1996).

For efficient off-site resource mobilization the following strategies may be adopted

- Establishment of district/block level governmental network to help and provide information to the farmers about the availability of potentially utilizable off-site nutrient resources and how the best these resources can be mobilized for crop production for a particular local situation.

- A multimedia approach including mobilization of farmers for group action is needed for mobilizing off-site resources to implement effective IPNS.
- For getting consistent performance of bio-fertilizers their use should be encouraged in those areas where agro-climatic situations favours optimal response to the use of specific bio-fertilizers. Random use of bio-fertilizers should be stopped.
- Grant of government subsidies on cost and transport of agro-industrial wastes, mine wastes/deposits and non-fertilizers grade rock phosphate, etc.

Resources Integration

Resources Integration is the guiding principle of the IPNS system. The basic objective of resources integration is not only to supplement the need for fertilizer nutrient but also to derive maximum benefits of positive interactive effects of the various nutrients resources applied to the soil to restore deleted/depleting soil fertility. It also involves the integration of the contributory role of soil processes with the other factors regulating eco-system functions, including those determining resource availability and access, and farmers decision making processes. Resource integration also ensures balanced crop nutrition and promotes synergistic interaction. Therefore, balanced fertilizer use must be based on the concept of integrated nutrient management for a cropping system, as this is the only viable strategy advocating accelerated and enhanced use of fertilizers with matching adoptions of organic manures and bio-fertilizers so that productivity is maintained for a sustainable agriculture (Goswami, 1997).

It is possible to the farmers to conceptualize the definition or the meaning of "resource Integration", but it is difficult in most cases to put the same into practice. The exact schedule to be followed for resource integration are invariably based on soil fertility for specific soil crop situations, and therefore requires decision support system at local level. Thus, the most important strategy under this component of IPNS is: resources integration in quantitative terms has to be worked out based on the soil test data for a particular soil-crop situation.

Resources Management

IPNS is often interpreted as a mere management system to improve "soil health" even though such an interpretation is very restrictive both in concept and in practice. It is true that mere meeting the nutritional requirements of the crops through "resources integration" alone cannot guarantee the sustainability of a production system, as sustainability is a multi-dimensional concept. Therefore, IPNS system must involve efficient management techniques to: A) Upgrade the efficiency of the input resources by Checking the possible losses of nutrients from soils, Optimizing nutrient resources combination, and Monitoring the flows of plant nutrient in order to achieve crop production goals. B) Alleviate soil limiting conditions of crop growth, such as, soil acidity, Salt accumulation and Soil compaction. Therefore, management techniques should ensure a stable equilibrium between opposing processes such as soil acidification and base saturation, salinization and desalinization, nutrient depletion and nutrient addition, and soil carbon loss and organic matter addition.

Concept of Soil Quality

The term and concept of soil quality evokes various responses depending on our scientific and social backgrounds. Presently, soil quality has been defined by some scientists as the "fitness for use and by others as the "capacity of the soil to function", whereas the definition of soil quality as proposed by Karlen et al. (1997b):

"The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation."

Traditionally, the quality of soil has been mainly associated with its productivity, whereas more recently, the definition has been expended to include the capacity of a soil to function within ecosystem environmental quality, and promote plant and animal health. Soil quality depends on a large number of

chemical, physical, biological and biochemical properties, and its characterization requires the selection of the properties most sensitive to change in management practices.

. The key soil functions as described by Karlen et al. (1997b) are given below:

1. Sustaining biological activity, diversity, and productivity;
2. Regulating and partitioning water and solute flow;
3. Filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition;
4. Storing and cycling materials and other elements within the earth's biosphere; and
5. Providing support of socioeconomic structures and protection for archeological treasures associated with human habitation.

As soil scientists, we are happy that the world scientific communities and policymakers have recognized that soil is a strategic asset of a nation and soil carbon, specifically in the form of soil organic matter, plays a central role in the functioning of soil to provide wide range of vital environmental goods and services. The SOM, as humus, has been recognized as a "source of human wealth on this planet" (Waksman 1938). All the under pinning physical, chemical and biological processes of soil function are directly dependent on the quality and quantity of soil organic matter and make the soil a natural capital and means of production for the ongoing supply of beneficial goods and services (Robinson et al. 2013). Thus , soil carbon is vital for all 4 classes of soil ecosystem services namely, supporting services, regulating services, provisioning services and cultural services (MEA 2005). Schmidt et al. (2011) mentioned soil fertility, water quality, erosion resistance and climate mitigation as important ecosystem services related to SOM.

Under the pressure of increasingly intensive land use, it is essential to protect and to enhance the full range of the essential life sustaining benefits that soil provide. The beneficial management of soil carbon is perhaps the most important means of human intervention to face this daunting challenge. The risks of losing soil organic C are many folds because of the potential consequences of a) Loss of soil fertility, reduced crop production and diminished other soil functions, and b) Increased greenhouse gas emissions and accelerated climate change.

The technological options for enhancing soil carbon sequestration generally include a strategic and judicious combination of practices such as,

- i) Tillage methods (conservation tillage, minimum use of mechanical tillage).
- ii) Ensuring better nutrient supply and sound nutrient cycling mechanisms to minimize losses.
- iii) Efficient water management to support optimal crop growth.
- iv) Controlling soil erosion through cover crop, mulch farming and residue management.
- v) Use of deep rooted cultivars of improved crop varieties.
- vi) Practice of crop rotation with high biomass yielding legumes.

Crop residues are composed of ligno-cellulosic materials (made up of hemi-cellulosic, cellulose and lignin). Hemi-cellulosic and cellulose can be degraded to simple sugars by the process of saccharization and successive enzymatic hydrolysis (as is being done in industrial production of ethanol from crop residues). In soil also, similar process operates with relatively slower rate resulting in gradual disappearance of hemi-cellulosic, and cellulosic components of the crop residues, while lignin component undergoes transformation to humus. Structural features of lignin vary from crop to crop. Rice straw contains less lignin than corn stover and wheat straw. Therefore, the extent of SOC sequestration largely depends on the quantity as well as quality of the biomass input added to the soil. Following the adoption of best management practices, the average rate of SOC sequestration is about 300 kg C/ha/year. It can be well illustrated with an example. Assuming that 10 tonnes of rice or wheat residues (containing 40% C, 0.5% N, 0.1% P and 0.05% S) is incorporated into soil, which will result formation of humus or SOC (containing 50% C, C:N ratio 12, C:P ratio 50 and C:S ratio 70) after humification. The original biomass(10 tonnes) contains 4000 kg C, 50 kg N, 10 kg P and 5 kg S. If the SOC sequestration rate is 20%, the resultant SOC will contain 800 kg C, 66.5 kg N, 16 kg P and 12 kg S, indicating that for the formation of 800 kg SOC, it will require additional 17 kg N, 6 kg P and 7 kg S. If the sequestration rate

is 10%, the resultant SOC will contain 400 kg, 33.5 kg N, 8 kg P and 6 kg S, suggesting that the formation of 400 kg SOC will release 16.5 kg N and 2 kg P only. Therefore, when rice/wheat/other cereal residues are incorporated into soil for nutrient cycling, the SOC sequestration is much less than 10%. It is important to note that to allow higher rate of SOC sequestration in soil, it requires additional amount of N, P & S. Richardson et al (2014) estimated that increasing SOC by 1 Mg C ha^{-1} into humus requires 73, 17 and 11 kg ha^{-1} of N, P & S, respectively. Without the availability of these essential nutrients, SOC concentration does not always increase even with long-term application of crop residues (Baker et al. 2007; Bisett et al. 2011). Hence, IPNS system involving leguminous crop residues containing higher amount of N,P,S and lignin are best suited for SOC sequestration as well as improving soil health.

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Long-term effect of balanced and Integrated Plant Nutrient Supply modules on crop productivity and soil health

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Introduction of high yielding varieties and use of high analysis fertilizer under irrigation condition resulted in green revolution in India. But continuous use of chemical fertilizer in indiscriminate manner without assessing soil affected productivity and environment adversely. Though fertilizer ensured the high production but at the same time accelerated mining of other nutrients by crops. This has led to hidden hunger of several other essential nutrients and sustainability of our agriculture has become venerable. Acceleration in mining of nutrient resulted in deficiency of Zn and S, in Indo-Gangatic Plain (IGP) and caused decline in productivity at several locations. The ever increasing population in subcontinent and shrinking natural resources (land and water) are building pressure to produce more and more same area in unit time. The pressure on natural resources in Indian context could be assessed from the fact that it supports 18 percent of human and over 15 percent of livestock of the world from 2.3 percent of world's geographical area. The overstressing on natural resources by disproportionate human and livestock population led to non-sustainability of many agro-systems. Therefore, it has become essential not only to sustain our agro-system but also to keep the pace of acceleration in food production with increasing demand of food and fiber.

Under present scenario it is beyond imagination to sustain the productivity without fertilizer input. But due to over-mining of the nutrient, Indian soils are showing negative balance to the tune of 10-12 million tons yr^{-1} and the negative balance is likely to increase in future even after using the full potential of fertilizer industry. To narrow down figure of negative balance increase in nutrient efficiency could be one of the options in addition to curtail the input cost and minimize ground the environmental pollution. The nutrients use efficiency (NUE) and productivity goes hand in hand compliments each other. Under this situation integrated plant nutrient supply (IPNS) also referred as integrated nutrient management (INM) not only reduce the nutrient gap between addition and removal but also ensures the higher nutrient use efficiency, sustainability of the system and minimize the environmental pollution. In this paper, attempts is made to have an over view of integrated plant nutrient supply on crop productivity and soil health.

What is Integrated Plant Nutrient Supply System

The survey of literature revealed that to convey the meaning of integrated plant nutrient different terms are being used viz., Integrated plant nutrient supply system (IPNS), integrated nutrient management (INM), balance nutrient etc. The basic principle of IPNS is based on nutrient supply through different sources i.e. FYM, crop residues, organic manure and fertilizer to plant for sustaining the productivity. The number of workers attempted to define IPNS by taking into account various parameters like productivity, maintaining living organism and socio-economic situation.

Integrated Plant Nutrition System (IPNS):It is defined as the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of benefit from all possible resources of plant nutrient in an integrated manner (Roy and Ange, 1991).

Integrated Plant Nutrition System (IPNS):IPNS is used to maintain or adjust soil fertility and plant nutrient supply to achieve a given level of crop production. This is done by optimizing the benefits from all possible sources of plant nutrient (FAO, 1998).

Integrated Nutrient Management (INM): INM is actually the technical and managerial component achieving the objective of IPNS under farm situations. It takes into account of all factors of soil and crop management including management of all other inputs such as water, agrochemicals amendment etc besides nutrients (Goswami, 1998).

Potential Sources of Organic Material

The annual potential of organic resources in the country available for use through excreta of livestock and human, crop residue, sewage sludge, municipal waste etc. is estimated to be around 20 m tons currently expected to be around 28 m tons together N, P₂O₅ and K₂O exclusive of micronutrient (Bhardwaj and Gaur, 1985). In addition to this following source are also available.

Organic Manure: Organic manures like FYM and composts are the important component of IPNS and should be assessed for the quantity available. According to one estimates nearly 800 m tons of organic manure available which comes out to be 2.5 t ha⁻¹ yr⁻¹ on an average if spread over 329 mha⁻¹ geographical area of the country.

Press mud: Sugarcane industry is the main sources of press mud which contains 1.0 to 2.5% N, 0.25 to 0.65% P and 0.4 to 0.85% K but being acidic in nature can be applied to alkaline soils. However, other type of press mud which is obtained from carbonation process contains lime and can be used in acidic soils. Nearly 2.7 m tons press mud is produced every year in our country.

Green Manure and BGA: Green manure is a good source of biologically fixed N and organic carbon. Several green manure crops like *Sesbania*, *Crotalaria juncea*, *Tephrosia purpurea* and sunhemp etc. are grown in our country. A 40-45 days old crop can supply 100-125 kg N which is almost equal to average N applied in most of the cereals crops. However, green manure is suited for rice based system. But practicing of green manure is restricted to a limited area like Kerala and North East part of the country where water is available during summer season. In North though water is available but farmers prefer to grow summer mung rather than growing green manure crop. In addition to green manure crop, growing of legume trees on bund or outside the field for the purpose of green manure is also practiced in pocket. Blue green algae (BGA) are also component of INM which is practiced in rice based cropping system. BGA is being practiced in Eastern and North Eastern part of the country.

Legume Residue: As discussed in previous section in North Western part of the country short duration summer mung is grown in between rice-wheat during fallow period. After harvesting pod, the C residue is incorporated in soil per ha which save 60 kg N (Rekhi and Meelu, 1983; Singh and Dwivedi, 1996).

Productivity of the System under INM

Since ages Indian farmers are firm believers of INM and were using all possible sources of nutrient including pond silt and earth scraping of fig tree in addition to FYM. The introduction of chemical fertilizers had led to little/no use of organic manure for a short period. But due to increasing cost of fertilizers farmers again started using organic manure to supplement the nutrient which reduced dependence on chemical fertilizer. A large volume of work was scanned and package of integrate nutrient management was made available for different agro-system (IISB Bulletin No. 2, 1998). Enhancing the productivity is a prime objective and priority of Indian agriculture to feed the ever growing population from shrinking natural resources. Inclusion of various components to supply the nutrient under INM depends on cropping system and availability of resources in a particular location. To study the impact of integrated nutrient management (INM) on productivity and soil health, long term fertilizer experiments play a vital role.

Rice- Wheat: Rice-wheat is most predominant cropping system of the country and contributes major portion of food basket. The yield data (Table 1) of Pantnagar (Mollisols), Barrackpore (Inceptisols) and Raipur (Vertisols) indicated that integration of nutrients resulted increase in productivity of the system at all the three places and incorporation FYM further enhanced the productivity. At Pantnagar application of 100% N alone for 34 years, average yields of rice and wheat recorded were 4780 and 3115 kg ha⁻¹.

Integration of P with N and K with NP resulted in increase in yield of rice to 4865 and 5095 kg ha⁻¹ and of wheat to 3779 and 3794 kg ha⁻¹ respectively. Incorporation of FYM with NP K further increased productivity of rice and wheat to 5788 and 4497 kg ha⁻¹ respectively. The similar trend in yield on integration of nutrient was also noted at other two locations with differing level of magnitude in productivity because of climatic condition. Increase in yield on incorporation of FYM is not only due to additional supply of major nutrients but also ruled out the hidden hunger of Zn and secondary nutrient at many places. Moreover, organic manure also helped in turnover process of nutrients in soil which is responsible for nutrient transformation in soil.

To evaluate the INM practice on productivity of rice and wheat number of trials were conducted throughout the country under AICRP Agronomy. The data summarized in table 2 indicated that combined use of fertilizer and organic manure (FYM) resulted in increase in larger productivity of the system with residual effect on subsequent wheat crop (Singh and Singh 1998). Eight years study on integrated nutrient management in rice-wheat in Vertisols (Singh et al., 2001) at Jabalpur revealed that conjunctive use of 5 t FYM and 6 t green manure (Parthenium) with 90 kg N not only sustained the productivity but also saved nearly 90-100 kg ha⁻¹ fertilizer N annually. In addition to saving of nitrogen, integrated nutrient management practices also improved the SOC and nutrient status of soil (Table 3).

Table 1: Effect of integrated nutrient management on average productivity of rice-wheat (kg ha⁻¹) cropping system under LTFE at different locations

Treatments	Pan Nagar (Uttarakhand)		Barrackpore* (West Bengal)		Raipur (Chhattisgarh)	
	1972 to 2015		1972 to 2015		1999-2015	
Crop	Rice	Wheat	Rice	Wheat	Rice	Wheat
Control	2934	1450	1507	747	2382	1057
100 % N	4782	3115	3194	1962	3678	1544
100 % NP	4864	3779	3573	2206	5095	2210
100 % NPK	5092	3794	3719	2321	5158	2239
NPK + FYM	5785	4497	3515	3620	5541	2697
100% NPK + GM	-	-	-	-	4666	1744
50% NPK + BGA	-	-	-	-	4225	1624
CD 5%	611	448	265	316	328	346

Saha et al., (2008)

Table 2: Effect of combined use of organic and inorganic fertilizer on average crop yields (t ha⁻¹) in rice-wheat at different location

Treatment	Location							
	Bhagalpur (87 trails)		Manipur (96 trails)		Ludhiana (5 years)			
Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	
F ₀ N ₆₀	F ₀ N ₆₀	4.21	2.75	441	1.04	5.6	2.8	
^a F ₁₂ N ₆₀	F ₁₂ N ₆₀	4.14	2.95	5.44	1.33	5.7	3.9	

At Ludhiana a= N₈₀ to rice and N₉₀ to wheat

Singh and Singh (1998)

Table 3: Integrated Nutrient management in rice wheat for 7 years and average productivity of rice-wheat (tha⁻¹) and nutrient status in Vertisol at Jabalpur

Treatment	Rice	Wheat	Nutrient Status after 7 years (mg kg)		
			OC%	P**	K*
N90	4.42	4.19	0.58	21.1	138
N180	5.08	4.70	0.71	18.7	125
N90 + FYM	4.95	4.49	0.74	40.1	230
N90 + GM	4.58	5.07	0.72	39.1	240
Initial	-		0.60	19.5	195

Singh et., al, 2001, *Singh et., al 2002 & **Singh et., al. 2007.

Soybean Wheat: Soybean-wheat is predominant cropping system of MP and becoming popular in Rajasthan and Maharashtra. Thirty five years data summarized in table 4 clearly indicated that integration of N, P and K sustained the yield at a higher level compared to application of N and NP. However, the maximum average productivity is recorded with conjunctive use of NPK and FYM. The impact of INM on productivity scenario recorded at Ranchi (Alfisols) is different. Continuous application of N alone compared to control indicates that N has adverse effect on productivity. At Palampur (Alfisols) continuous application N resulted sharp decline in yield with time and at present there was zero yields in this particular plot. However integration of PK along with FYM/lime sustained the productivity of the system over last 43 years. (Table 4). Integration of P and PK with N resulted increase in yield of soybean from 196 Kg ha⁻¹ (100% N alone) to 861 and 1596 Kg ha⁻¹ respectively and the corresponding yields of wheat recorded were 275 (100% N) 2432 kg ha⁻¹ and 3089 Kg ha⁻¹ (Table 4) It is interesting to note that integration of NPK with FYM further increased the yield of both soybean and wheat. At Ranchi use of lime as a component of INM also improved the productivity significantly. Thus big jump in yield indicates that integrated nutrient management becomes more important in soils which have poor buffering capacity.

Table 4: Effect of integrated nutrient management on average productivity of soybean/ maize-wheat system under LTFE at different locations

Treatments	Ranchi(Jharkhand) ^a		Jabalpur (M P) ^b		Palampur (H P) ^c	
	1972 to 2015		1972 to 2015		1999-2015	
Crop	Soybean	Wheat	Soybean	Wheat	Maize	Wheat
Control	617	705	838	1206	261	365
100 % N	196	275	1049	1651	149 ^d	142 ^d
100 % NP	861	2432	1728	4034	1953	1642
100 % NPK	1596	3089	1888	4353	3175	2289
NPK + FYM	1932	3533	2069	4770	4588	3029
NPK + Lime	1771	3218	-	-	5580	2480
CD 5%	212	390	282	441	706	502

^a at present yields are zero. ^b a Dwivedi et al., (2007), ^c b Mahapatra et al., (2007), ^d c Sharma et al., (2005).

Seven years study on soybean-wheat at IISS farm also demonstrated that integration of nutrient (FYM and fertilizer) sustained the yield at higher level compared to sole application of either organic or fertilizer (Rao et. al. 1998). Similarly, trials conducted at farmers' field in Sehore and Bhopal districts for three years (Table 5) further confirmed that integrated nutrient management is the best option as far as productivity and profit of the farmers are concerned (Singh et. al. 2008).

Table 5: Effect of INM on productivity of soybean wheat (t ha⁻¹) and economics.

Treatment	Soybean	Wheat	Total output cost*
FYM	1.81	3.87	45631
PM	1.90	3.69	46390
IPNS	1.97	4.32	50392
Conventional	1.74	3.98	45617
CD (5%)	NS	0.39	-

*The cost of output was calculated on the basis of price prevailed during that period.

Maize-Wheat: Maize-wheat is another important cropping system of North-West India. The yield data of 43 years old maize-wheat cropping system at Ludhiana and 18 years old experiment at Udaipur and Delhi indicated that integration of P and K with N enhanced the productivity of the cropping system. Integration of P with N resulted in increase in yield of maize from 1871 Kg ha⁻¹ (N alone) to 3009 and wheat from 2932 Kg ha⁻¹ to 4508 Kg ha⁻¹ At Ludhiana. Addition K did not have much effect but incorporation of FYM increased productivity of both the crops (Table 6). Similar effect of integration of nutrient and organic manure on crop productivity was recorded in New Delhi and Udaipur

Table 6: Effect of integrated nutrient management on average productivity (kg ha⁻¹) maize-wheat system and LTFE

Treatments	Ludhiana (Punjab)		New Delhi		Udaipur (Raj)	
	1972 to 2015		1995 to 2015		1997 to 2015	
Crop	Maize	Wheat	Maize	Wheat	Maize	Wheat
Control	789	1241	1182	2403	2000	1941
100 % N	1871	2932	1577	3564	2550	3206
100 % NP	3009	4508	2993	4485	3297	3883
100 % NPK	3227	4739	3151	4514	3364	4209
NPK + FYM	3901	5149	3551	4959	3590	4757
CD 5%	244	266	192	286	223	242

Finger millet-maize: Finger millet-maize covers large area in southern India. The yield data of both finger millet and maize indicate that integration of all the three major nutrients (NPK) always had the larger productivity compared to application of N and NP. Integration of FYM with NPK further boosted the productivity of the system (Table 7).

Rice-rice: Rice-rice is quite common in some parts of southern and eastern states of the country. The 10 year average yield data (Table 7) indicated that integrated nutrient management is the only option to sustain productivity of rice-rice Alfisols of Pattambi (Kerala). At Pattambi green manure and liming are essential components of INM for sustaining the productivity at higher level.

Thus, data generated under long-term experiment and in other studies clearly demonstrated that integrated nutrient management is the only option to sustain the productivity at higher level. Application of FYM ensures the sustainability at higher level by taking care of the hidden hunger of micro and secondary nutrients which otherwise could have been limiting factor in sustaining the productivity and NUE. Applications of FYM in addition to supply of nutrient also act as conditioner for physical condition of soil like infiltration and bulk density which improves aeration and water movement in soil required for better root and plant growth. In Alfisols of Ranchi, Bangalore and Palampur application N alone had adverse effect on productivity. The reason for decline in productivity in Alfisols is due to nonavailability of P and K due reduction in soil pH on application of N alone. Whereas at Jabalpur P and K were not limiting nutrient for quite some which made possible to sustain the yield. However, application of P along with N and K along with NP had + ve effect on productivity of rice-wheat, soybean-wheat and maize-wheat system.

Table 7: Effect of integrated nutrient management on average productivity (kg ha⁻¹) of finger-millet and rice-rice system under LTFE

Treatments	Bangalore		Coimbatore		Pattambi	
	1987-2014		1971-2014		1998-2014	
Crop	F. Millet	Maize	F. Millet	Maize	Rice	Rice
Control	582	284	1094	917	1532	2120
100 % N	540	387	1346	1179	2120	3053
100 % NP	1248	1644	2976	3079	1997	2902
100 % NPK	4241	3172	3063	3211	2210	3020
NPK + FYM	4567	3478	3537	3767	3162	3329
NPK + GM	-	-	-	-	3556	3780
NPK + Lime	4462	3297	-	-	3234	3436
CD 5%	126	566	400	316	447	351

Impact on Soil pH

Soil pH is an important intrinsic property of soil which usually does not change easily. However, long term use of fertilizer indicated that continuous use of nitrogenous fertilizer or use of ammonium sulphate as a source of nitrogen resulted decline in pH which had adverse effect on productivity of crops. Continuous use of urea alone and resulted decline in soil pH but the effect of fertilizer is more serious in Alfisols because of poor buffering capacity (Table 8).

Table 8: Effect of nutrient management on soil pH in Alfisols of Palampur(H P) and Ranchi (Jharkhand)

Treatment	Alfisols		Vertisols	
	Ranchi	Palampur	Jabalpur	Akola
Initial	5.5	5.8	7.6	8.1
100% N	4.4	4.4	7.6	7.8
100% NP	4.8	5.0	7.5	7.8
100% NPK	4.6	5.1	7.4	7.8
100% NPK+FYM	4.7	5.2	7.4	7.8
100% NPK+ lime	5.7	6.4	-	-

Table 9: Nitrogen use efficiency in different crops as affected by balanced and imbalanced use of nutrient in long-term fertilizer experiment

Soil Type	Location	Crop	Mean nitrogen use efficiency, %			
			100% N	100% NP	100% NPK	100% NPK+FYM
Inceptisol	Ludhiana	Maize	16.7	23.5	36.4	40.2
Alfisol	Palampur	Maize	6.4	34.7	52.6	63.7
Mollisol	Pantnagar	Rice	37.5	40.7	44.4	61.7
Inceptisol	Ludhiana	Wheat	32.0	50.6	63.1	67.8
Alfisol	Palampur	Wheat	1.9	35.6	50.6	72.6
Mollisol	Pantnagar	Wheat	42.4	46.1	48.4	47.9

Table 10: Phosphorus and K use efficiency as affected by integrated use of nutrient

Soil Type	Location	Crop	P use efficiency (%)			K use efficiency (%)	
			100% NP	100% NPK	100%NPK +FYM	100% NPK	100%NPK +FYM
Ludhiana	Inceptisol	Maize	10.3	21.4	26.3	43.8	58.2
Palampur	Alfisol	Maize	21.8	35.6	51.1	23.0	38.9
Pantnagar	Mollisol	Rice	18.2	23.3	53.0	34.5	108.3
Ludhiana	Inceptisol	Wheat	20.6	30.7	34.8	88.1	112.8
Palampur	Alfisol	Wheat	10.7	15.2	24.6	22.6	66.8
Pantnagar	Mollisol	Wheat	11.2	10.4	23.3	13.7	35.8

Soil health in relation to nutrient management

To sustain productivity for long period of time it is essential to maintain soil health. It is also our moral responsibility to pass on a healthy soil to next generation. Sometimes misuse of nutrient may lead to deterioration of soil. Therefore to avoid such situation nutrient management may become important.

Soil Organic Carbon

Data depicted in Table 11 on soil organic carbon (SOC) revealed that continuous balanced nutrients application maintained SOC whereas incorporation of FYM resulted in build-up in SOC in Alfisols of Bangalore and Palampur. At Ranchi, only NPK+FYM could maintain SOC whereas in all other treatments decline in SOC is recorded. Thus, results indicate that under high rainfall incorporation of FYM is essential to sustain soil productivity.

Organic carbon data in Inceptisol of Ludhiana and Vertisol of Jabalpur and Alfisol of Bangalore revealed that balanced application of fertilizer maintained the soil organic carbon and the yields (Table 4 & 5) are also sustained.

Table 11: Soil organic status (g kg⁻¹) in long term fertilizer experiments

Locations	Initial	NP	NPK	NPK+FYM
Ludhiana	2.2	3.3	3.6	5.2
New Delhi	4.4	3.9	4.4	5.5
Udaipur	6.9	7.1	7.8	9.9
Jagtial	7.9	1.0	1.0	1.1
Jabalpur	5.7	6.5	7.4	9.6
Akola	4.6	4.9	5.1	6.8
Coimbatore	3.0	6.7	7.0	9.8
Palampur	7.8	9.4	9.7	1.3
Bangalore	4.6	4.7	4.9	5.7
Pantnagar	1.5	8.5	8.7	1.6
Barrackpore	7.0	4.7	4.6	6.8
Ranchi	4.5	3.8	3.9	4.5
Raipur	6.2	6.0	6.1	7.0

Nutrient status

Perusal of data given in table 12 revealed that the available status of N in all the soils except at Palampur remained more or less same. It is because of application of all the three major nutrients which are responsible for good yield and thereby incorporating good amount of organic material to soil through root biomass. The increase in available N is because of soybean which adds nearly 2000 kg C and nearly 30 kg N to soil. Continuous application of P resulted increase in P status at all place though differ in magnitude, may be because of inherent P fixation capacity of soil and crop requirement. The build up of P in soil is expected as the amount of P applied is larger than the uptake. On contrary to P, significant decline in available K was observed in all the soil. Obviously it is due to larger uptake of K than applied.

Soil physical properties

The physical condition of soils facilitated to microbial activity, root proliferation and water transmission characteristics which help in regular nutrient supply and plant growth. Bulk density and mean weight diameters (MWD) are soil properties which indicate soil condition. The results indicated that in general balanced application of nutrient (NPK). Integrated nutrient management resulted decline in bulk density and increase in MWD irrespective of soils. However, in Alfisols imbalance use of nutrient (100% N) had adverse effect on bulk density and MWD at Palampur (Table 13).

Table 12: Available N, P and K status in 100% NPK treatments at various LTFEs centres after 2015

Center	Cropping sequence	Initial status, kg/ha			Avail. status, kg/ha		
		N	P	K	N	P	K
Bangalore	Finger millet-Maize	257	34	123	258	86	148
Coimbtore	Finger millet-Maize	178	11	810	190	29	584
Ludhiana	Maize-Wheat	100	9	100	107	82	91
Delhi	Maize-Wheat	210	16	155	225	25	291
Palampur	Maize-Wheat	729	12	194	328	126	164
Udaipur	Maize-Wheat	245	22	671	255	23	647
Ranchi	Soybean-Wheat	236	12	158	351	77	137
Jabalpur	Soybean-Wheat	226	8	370	240	29	278
Pantnagar	Rice-Wheat	392	18	125	229	18	129

Table 13: Effect of nutrient management on soil physical properties

Treatment	Palampur (Alfisols)		Jabalpur		Ludhiana (Inceptisols)	
	B.D. (Mg m ⁻³)	MWD (mm)	B.D. (Mg m ⁻³)	MWD (mm)	B.D. (Mg m ⁻³)	MWD (mm)
Initial	1.31	-	-	-	-	-
Control	1.32	1.33	1.30	0.92	1.59	0.31
100% N	1.36	0.89	1.30	0.93	1.54	0.34
100% NP	1.22	1.57	1.29	1.04	1.53	0.38
100% NPK	1.17	1.68	1.28	1.05	1.53	0.41
100% NPK+FYM	1.13	2.70	1.25	1.18	1.49	0.52

Microbial soil properties

In soil nutrients are mediated through soil organisms and their activity is assessed by soil microbial biomass (SMBC) and dehydrogenase activity (DHA) in soil. The data presented in table 14 indicates in general application of nutrient resulted increase in SMBC and DHA but more pronounced under balanced and integrated management of nutrient irrespective of soil compared to control. However, in Alfisols imbalanced use of nutrient had adverse effect on soil microbial biomass carbon and DHA.

Table 14: Nutrient management and microbial properties of soil at different LTFEs

Treatment	Palampur		Coimbatore		Ludhiana (Inceptisols)	
	MBC (kg/g)	DHA (ugTFFg ⁻¹)	MBC (mg kg ⁻¹)	DHA	MBC (kg/g ⁻¹)	DHA
Control	276	18	203	-	139	22
100% N	163	12	227	-	167	24
100% NP	188	26	258	-	185	35
100% NPK	828	35	280	-	210	30
100% NPK+FYM	980	38	385	-	228	76

Effect of different IPNS module on crop productivity and soil health

Data presented in table 15 revealed that application of balanced nutrient resulted highest productivity of maize but yield recorded on application of nutrients through different IPNS module using FYM, poultry manure and urban compost along with 75% per cent of recommended dose of fertilizer also maintained the similar yield. However, IPNS modules maintained more available status of NPK. Which means application of organic manure reduced the dependence on fertilizer to the extent of 25 percent in

addition to sustainability of soil health. Otherwise the organic waste of poultry and municipal waste which is not being used will pollute the atmosphere. Thus IPNS module performance is better than sole use of fertilizer.

Table 15: Effect of different IPNS module on yield (tha⁻¹) of Maize and Chick pea and soil health (5 years average yield)

Treatment Nutrient applied in maize		Yield, tha ⁻¹		Org. C %	Soil health parameters (available nutrient kg ha ⁻¹)		
		Maize	Chickpea		N	P	K
T ₁	Control	2.10	1.20	0.42	180	9.3	318
T ₂	120- 60- 30 / 20-60- 20*	5.08	1.99	0.51	213	13.9	434
T ₃	75% NPK of T2	4.48	1.55	0.46	202	11.5	439
T ₄	75% NPK +5 t FYM	5.90	1.91	0.48	222	19.1	503
T ₅	75% NPK + 1 t PM	4.96	1.76	0.46	209	16.8	430
T ₆	75%NPK + 5 t UC	4.89	1.78	0.52	216	14.7	458
LSD 5%		0.47	0.24	0.075	11.2	2.4	34.2

Note: In all other treatments (chickpea was grown on residual fertilizer) * Fertilizer applied in Chick pea

Conclusions

Thus from the data generated under long-term fertilizer experiments it is concluded that balanced and integrated Plant nutrient supply not only sustained the crop productivity but also improved the soil properties. Data also ruled out the notion that use of chemical fertilizer resulted in distraction of soil organic carbon. However, imbalanced use of nutrient under some situation resulted in depletion of SOC. irrespective soil type balanced and integrated plant nutrient supply improved soil physical condition and microbial activity too. Thus balanced and IPNS is the only option to sustain the crop productivity but also improve the soil health on long term basis.

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Role of integrated plant nutrient management in mitigation and adaptations to climate change

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Introduction

Climate change is unavoidable and associated weather extremes such as high temperature and heat waves, increased frequency of drought and high intensity rainfall causing floods, are the issues of concern. Circumstantial evidences almost confirm researchers' early predictions of a changing climate and a warming world. The trend of changes also establishes the primary influence of increased greenhouse gas concentration on the global warming and the consequential events. The global mean surface air temperature has increased by about 0.85 [0.65 to 1.06] °C over the period 1880 to 2012 (IPCC, AR5, 2014). Changes will vary from region to region. The period from 1983 to 2012 was likely the warmest 30-year-period in the last 1400 years in the northern hemisphere. The global mean surface temperature is projected to increase further under all the representative concentration pathways (RCPs). This is because of the increase in the global abundance of the three key greenhouse gases (GHGs) namely, CO₂, CH₄ and N₂O in the atmosphere. Since 1750, the concentrations of the three GHGs, viz. carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) have increased by 40%, 150% and 20% respectively. The radiative forcing of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) is very likely (> 90% probability) increasing at a faster rate during the current era than any other time in the last 10,000 years. As per the 5th Assessment Report (AR) of the Intergovernmental Panel on Climate Change (IPCC), out of the total anthropogenic CO₂ emissions between 1750 and 2011, about half have occurred in the last 40 Years.

The atmospheric CO₂ concentration has increased from 270 $\mu\text{mol mol}^{-1}$ in the pre - Industrial era to about 410 $\mu\text{mol mol}^{-1}$ in 2017 and the business-as-usual path of energy use based on fossil fuel consumption may raise it to 900 to 1100 $\mu\text{mol mol}^{-1}$ by the end of 21st century. The current atmospheric CO₂ concentration is probably the highest since last 20 million years. The current rate of increase at about 2 $\mu\text{mol mol}^{-1} \text{ yr}^{-1}$ is also the highest since the monitoring commenced in 1959.

Thus, climate change is manifested basically in the following three different ways : (1) Increase in concentration of green house gases (CO₂, CH₄ and N₂O), (2) Global warming and (3) Increase in extreme weather events. Because of the higher abundance of the CO₂, the total radiative forcing of this gas is higher and thus is much talked about in context of climate change.

Tackling climate change impacts

To tackle the impacts of climate change, two types of measures are generally used : (1) mitigation and (2) adaptation. The IPCC defines mitigation as an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases. Some examples of mitigation measures include higher use of renewable energy, practicing energy efficiency, electrification of industrial activities etc. On the other hand, adaptation is the adjustment to the natural or human systems to a new or changing environment. Adaptation to climate change includes practices and measures that reduce the vulnerability to the effects of climate change. It also includes harvesting the most of any potential benefits or beneficial opportunities associated with climate change (for example, longer and conducive crop growing seasons, enhanced crop yields in certain regions). Some examples of adaptation measures include reforestation, restoration of degraded lands, precautionary measures to avoid harmful effects of heat stress etc. However, certain

measures can have both mitigation and adaptation value. For instance, conservation tillage can show a reduction in carbon emission, can enhance the carbon storage in soil and at the same time can impart resilience to food production under drought conditions due to higher soil moisture retention. To eliminate or reduce the risk of climate change to human life and property, both policy instruments and technology must be used in the context of sustainable development. The United Nations Framework Convention on Climate Change (UNFCCC) has explicitly described three key conditions for greenhouse gas stabilization in the atmosphere, (1) That, it should take place within a time frame sufficient to allow ecosystems to adapt naturally to climate change, (2) That, food production is not threatened and (3) That, economic development should proceed in a sustainable manner.

Agriculture, Forestry and Other Land Use (AFOLU)

AFOLU has a central role in food security and sustainable development. As per IPCC (2014), the AFOLU sector accounts for about 25% (about 10 – 12 billion ton CO₂ equivalent / yr) of the net anthropogenic GHG emissions. These take place mainly from deforestation, emissions from soil and nutrient application and CH₄ emission from livestock sector. Out of the total emission caused by human activities, agriculture sector is responsible for 25% of CO₂, (largely from deforestation), 50% of CH₄ (Paddy cultivation and enteric fermentation), and about 75% of N₂O (mostly from excessive chemical fertilizer use). Despite recent estimates indicating a decline in CO₂ flux in the AFOLU sector largely due to decreasing deforestation rates and increased afforestation, there is high level of uncertainty in this sector. Nevertheless, there is high agreement with medium evidence on the possibility of the AFOLU sector becoming a net CO₂ sink in future. The most cost-effective mitigation options in agriculture are soil nutrient management in crop fields, soil carbon sequestration, grazing land management, and restoration of organic soils. Some mitigation options in the AFOLU sector such as soil carbon sequestration in crop fields and forest sectors may be vulnerable to climate change and also are beset with high levels of leakages. Further, policies governing agriculture and forest management are more effective in presence of a synergy between mitigation and adaptation measures.

Integrated plant nutrient supply / management (IPNS)

Integrated Plant Nutrient Supply / Management (IPNS) have been long associated with agriculture practice. However before Green Revolution, agriculture was mostly characterized by low input – low output system with less dependence on inorganic chemical fertilizers. Introduction of high yielding varieties and increase of cropping intensity led to widespread nutrient mining from soil and a negative nutrient balance in soils of major cropping systems. This led to laying much emphasis on the IPNS as the fertilizer response ratio decreased drastically in many South Asian countries. The IPNS is a system where the nutrient demands of crops are met from a combination of nutrient sources including chemical fertilizers, organics, biofertilizers and green manures. Thus the major components of IPNS are:

- Balanced fertilization
- Chemical fertilizers
- Organic sources of nutrients including non-conventional sources
- Crop residue management : Of late, residue burning has been a serious problem in the Indian sub-continent. This apart from contributing to green house gas emission, deprives the soil of several benefits associated with recycling of crop residues. About 30% N, 60-70% P and 75% K contained in crop residues is available to the first crop and rest to subsequent crop. Crop residues apart from acting as a mulch, adds soil organic matter content, enhances nutrient use efficiency and improves soil physical properties and microbial activity.
- Green manures
- Biofertilizers : Biofertilizers can be a significant contributor to supply plant nutrients to supplement chemical fertilizers. Rhizobium is an effective bio-fertilizer for legumes with potential to save about 25-50% of the recommended dose of N apart from a substantial residual effect.

IPNS is a climate smart soil management system

The IPNS has a substantial role in reducing carbon foot print in food production systems and plays a vital role in imparting mitigation and adaptation value. Some of the basic principles by which IPNS governs the mitigation aspect in soil management systems include reduced N₂O emission, reduced CH₄ emission and increased soil C storage. At the same time, IPNS also adds adaptation value to the management system primarily through higher soil moisture storage so as to withstand drought conditions, better soil structure for favourable infiltration and water movement, increased biological activity to supply plant nutrients through altered rates of soil processes and finally through a higher biological productivity even under stress conditions. The commonly followed IPNS practices along with their mitigation and adaptation values are discussed below.

Site specific nutrient management

It is also known as need based fertilizer application where nutrients/fertilizers are added depending upon the plant demand and soil test value. It has mostly been used for N fertilizer management. Use of leaf colour charts and chlorophyll meter for N management in rice crop in Asian countries is one of the leading examples of need based fertilizer management and studies have shown a reduction in use of N by 12 to 25% in India without any yield loss (Ali et al. 2015).

Organic manures

In agriculture, organic manures such as farmyard manure, vermicompost, green manure, and azolla have been used in soil nutrient management depending on the availability of the resources and farmers' convenience. However, one of the major limitations of these manures is their low nutrient content and thus are required in bulk. For example, most organic manures contain 0.5 to 1.5% N as compared to 25-46% N in mineral fertilizers. Despite low nutrient value, organic manures improve soil quality by increasing the soil carbon content and enhancing biological activity (Table 1). Manures like farm yard manures as are applied after a decomposition cycle adds stability to the C added to the soil. Manure addition enhances soil carbon sequestration (carbon sinks) and also enhances physical protection of soil C through better aggregation. However, enhanced soil carbon through addition of organic materials to soil does not always mean contribution to climate change mitigation. Conditions, where, carbon is stabilized or physically protected through aggregation actually add to the mitigation and adaptation value (Tesfai et al., 2016).

Table 1: Possible effects of organic manure applications in carbon economy in Agriculture

Attribute	Mitigation/Adaptation	Mechanisms
Higher soil carbon	Adaptation	Withstand stress
Low application of chemical fertilizers	Mitigation	Low N ₂ O emission
Higher soil moisture storage	Adaptation	Withstand drought
Increased yield	Adaptation	Higher productivity due to better soil quality

Biofertilizer application

Biofertilizers are products or formulations that contain living cells of different types of microorganisms and they are used either as seed or soil application. After being applied, the microbial cells multiply and eventually colonize in the rhizosphere or the interior of the plant and help in solubilising or increasing the availability of plant nutrients. Rhizobium is a symbiotic N fixer with legumes where as Azospirillum and Azobacter are free living N fixing bacteria. Phosphate solubilizing bacteria like Bacillus help in converting P from insoluble forms to soluble forms. Several studies report saving in N and P through use of biofertilizers, though the extent varies depending upon the soil and climate conditions. Tesfai et al., (2016) reported a saving of about 30% urea due to soil test based fertilizer application along with biofertilizers. The treatments having cyanobacteria (blue green algae) application apart from registering higher rice yields, showed lower methane flux as compared to the flooded rice. Reduced

requirement of N from chemical fertilizers due to supplementation from biofertilizers is also likely to reduce the N_2O flux from rice ecosystems. From the point of global warming potential, CH_4 and N_2O are more potent than CO_2 . Thus, use of biofertilizers can be considered to be a potential climate smart nutrient management strategy (Table 2).

Table 2: Contributions of biofertilizer applications in carbon economy in agriculture

Attribute	Mitigation/Adaptation	Mechanism
Improved soil structure	Adaptation	Addition of biomass C and better microbial activity
Saving of chemical fertilizer	Mitigation	Carbon cost of fertilizer manufacturing
Reduced CH_4 and N_2O emission	Mitigation	Global warming potential of CH_4 and N_2O are higher than CO_2
Higher crop yield	Adaptation	Productivity

No-till and conservation tillage

No-till system is the most widely studied agricultural management system to improve carbon economy. However, it depends on specialized planting equipment and herbicides. The major benefits accrued from a no-till system include accretion in soil C due to low disturbance of soil in absence of any tillage. The basic mechanism involved is higher aggregation which in turn gives physical protection to soil C. However, most of the studies have demonstrated that no-till can increase soil C, particularly at the soil surface (Six et al., 2004; West and Post, 2002). Further, to achieve a substantial gain in soil C, it is vital to maintain the soil with no-till systems without any interruption. Conservation tillage is a modified form of no-tillage system where tillage is practiced to some extent, but stores soil C using similar principle as that under no-till system. Despite the above, beneficial effects of no-till and conservation tillage systems are not conclusive. In the short term, controlling weeds and managing residue-borne diseases pose hinderances to a wider adoption of these systems (Giller et al., 2009). These systems also fail in dry regions such as that in Africa due to long dry seasons resulting in little scope for cover crops to survive and thus implying the requirement of water conservation for these systems to succeed (Rockstrom 2009).

Cover crops and crop rotations

While conservation tillage systems protect soil C primarily due to low disturbances of soil and thus giving a physical protection to soil C, cover crops and crop rotations particularly with legumes supply C input to soil. Further, cover crops have shown benefits of suppressing weeds and reducing soil erosion and thus reducing the loss of plant nutrients through runoff or uptake by weeds. Some recent studies have demonstrated that more diverse crop rotations contribute to soil carbon and higher soil microbial activity (McDaniel et al., 2014). Inclusion of different crops in a rotation releases greater variety of carbon compounds to soil and some of them have higher mean residence time. Crop rotations also break the monotony of specific cropping systems and associated problems and also explore nutrient demand from varied zones in soil profile.

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Composting technology and strategies for integration in IPNS

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The history of composting dates back to the history of early agriculture. Modern composting got its start in India where, Sir Albert Howard (1921), a government agronomist, developed the so called Indore method of composting. His method called for three parts garden clippings to one part manure or kitchen waste arranged in layers and mixed periodically. Howard published his ideas in 1940 in the book "An Agricultural Testament". The first articulate advocate of Howard's method in the United States was J.I. Rodale (1971). In this lecture, several methods followed in India and abroad and recent techniques of composting has been discussed and also presented its effects on soil health under integrated nutrient management system.

In India, rural wastes (farmyard waste, household waste, agricultural wastes etc) are commonly composted by Pit method (15'x 6' x 6': L x W x H), Trench method (15'x 6'x 3': L x W x H) or Heap method (30' x 6' x 3': L x W x H). The size of the pits depends upon the material availability. The compost is usually ready in about 6-7 months after 2-3 turnings at 15 days intervals. There are various methods, traditional as well as modern, manual as well as mechanical which are scientifically designed and tested for good quality compost production. Some methods of composting and their salient features are described below.

Indore Method of Composting

Howard and Wad (1931) developed this method in which following are the major steps and operations:

- A pit of 9' Long (L) x5' Wide (W) x3' H (high) is prepared (1 ft = 30 cm). This pit is partitioned into 3 equal parts of which, two parts are filled and third part is left empty for turning.
- Inputs include dry and green agricultural waste, grasses, etc. soaked with water and cattle-dung slurry followed by cattle-dung and soil is spread in a 1-2 inches thick layer.
- Only two parts of the pit is filled layer by layer up to the height of 4 feet, keeping third part empty for turning. After filling, the tank is sealed with 3" thick layer of soil covered with cow dung and mud plaster. The process is accelerated by turnings (Fig 3.2), whereby aeration, mixing of composting materials and moistening is done. (if necessary).

This results in almost total decomposition of the matter, yielding brown homogeneous compost in about three months. The compost resembles the traditional FYM in appearance and properties. The average nutrient content of compost prepared by this method is 0.8 % N, 0.3-0.5% P₂O₅ and 1-1.5% K₂O. This method of composting however, involves a considerable labour in building up the heap/pit to proper shape and periodical turnings rendering it impracticable and expensive, where large quantities of materials have to be processed. A major disadvantage of this process is the heavy losses of organic matter and nitrogen (40-50 % of the initial).

Bangalore Method of Composting

This method was developed by Acharya and Subramanian (1939). It is a heat fermentation method for the composting of city garbage and night soil in pit method. The method is initially aerobic but later anaerobic and attempts at greater conservation of nutrients as compared to the Indore method. It involves the following steps:

- The city refuse and night soil are spread in alternate layers of 15 cm and 5 cm with a final layer of refuse on the top. The materials are then covered with a thin layer of soil. Heaps are prepared as in the Indore method except that each heap is sealed with a mud plaster which increased the temperature due to anaerobic fermentation.
- The decomposition is mostly anaerobic and comparatively slow. The major disadvantage is turning. There is a reduction of C/N ratio to less than 20:1
- After four months, the compost may be ready for use, although some workers place a much longer time frame of 32 weeks.

NADEP Method of Composting

This method was developed by N.D. Pandharipande after whom it is named and abbreviated as NADEP. The methods are described below:

NADEP compost is prepared in an aerobic tank made of bricks and cement. The size of the tank is 12' x 5' x 3' (L x W x H) (1' = 30 cm). All the four walls of the tank are provided with 6" vents by removing every alternate brick after the height of 1 ft. from bottom for aeration. Tank can be constructed of mud or cement mortar. Before filling, the tank is plastered with dilute cattle dung slurry to facilitate bacterial activity from all four sides. It is then filled in definite layers consisting of the following sub-layers:

Sub-layer 1: 4 to 6" thick layer of fine sticks or stems of pigeonpea/tur/arhar stalks or cotton stalks. This is provided for the initial layer only to facilitate aeration, followed by 4 to 6" layer of dry and green biomass (material to be composted).

Sub-layer 2: Approximately 4 kg cattle-dung is mixed with 100 litres of water. This slurry is sprinkled thoroughly on the agricultural waste to facilitate microbial activity. It is used only as a bacterial inoculum.

Sub-layer 3: Approximately 60 kg of soil is sprinkled uniformly over the biomass layer. Addition of soil serves three purpose (i) retention of moisture (ii) soil micro-flora helps in biodegradation and (iii) it acts as buffer and controls pH of the medium during decomposition. As the tank height is approximately 3' of 10-12 layers (sub layers 1-3 in each layer) can be accommodated in a tank. After filling the tank, biomass is covered with 3" thick layer of soil and sealed with cattle-dung and mud plaster. After 15-30 days of filling, the organic biomass in the tank gets automatically reduced to 2 ft. At this time, without disturbing the initial sealing layer, tank is refilled by giving 2-3 similar layers over it and is resealed. After this filling, the tank is not disturbed for 3 months, except that it is moistened every 6-15 days according to the weather conditions. From each tank, approximately 2.5 tonnes of compost is prepared within 3-4 months.

ADCO process: Hutchinson and Richards (1921) have developed this process in Agricultural Development Company (ADCO). The size of the pits used is 15' x 6' x 6' (L x W x H): In this process, nitrogen fertilizers such as ammonium sulphate or urea are utilized for the decomposition of carbonaceous (wide C: N ratio) materials. This reduces the C:N ratio to about 30-40:1 and then is allowed to decompose for 5-6 months in the pit. Super phosphate may be added to fortify the concentration of the manure. 2-3 turnings are required in this process. After six months, the compost is ready use.

Modified Indore process (USA): In USA, all refinements and changes in the original Indore process were summarized (Wiley, 1967 and Poincelot and Day, 1973). Main features of the modified process are:

- On a leveled and well drained site, a typical pit is built which is about 7' or more in length. 7' wide at the base and 5' high. A container is built around the pile to cover it and protect it from the wind, which tends to dry the pile from outside.
- Piling is often started with an 8 inches layer of carbonaceous wastes such as leaves, hay, straw, sawdust, woodchips, waste newspaper having wider C:N ratio followed by 4 inches of N-rich materials such as fresh grass, weeds or garden plant residues, fresh or dry FYM and sewage sludge. The different layers of carbonaceous materials are required for efficient decomposition of the piles

- Proper aeration should be facilitated for rapid decomposition and quick development of high temperature.
- Compost will be ready after 3 months, if the pile is started in the spring or summer.

Windrow method: In Connecticut, USA, the most successful municipal composting has been done with leaf windrows method (Randazzo 1970, Rodale 1971).

Pile of any convenient length, about 8-12' wide and 4 – 8' high is required. If the pile is too high, it will become compact and reduce pore space. A height of 8' is optimal for heat retention. Compressed pile requires increased turnings to combat anaerobic conditions for raising the temperature. Studies at University of California, Berkley (1953) showed that this method was satisfactory for composting of city fresh garbage in 4 months.

Beccari process: This process is presently used in Italy, France and USA. Rodale and staff(1971) improved this method with a chimney for continuous loading. In this device, one air valve is fixed on the top and unloads from the front. Initially the material is digested anaerobically at 65° C and the process becomes partially aerobic after about 18 days. Compost can be prepared within 35 to 40 days.

Vuil-Afvoer-Maatschappij process: This process has been used for some times in the Netherlands. Refuse is delivered by rail for final product from composting municipal wastes, takes 3 to 5 months. The decomposed materials can be shredded and then screened to remove stone and debris before use.

Chinese high temperature stack: A high temperature system has been developed by this method in China where a considerable quantity of night soil is returned to agriculture.

This technique involves a number of air channels by using bamboo poles and covering the outside of the heap with a thin layer of soil. The length, height and width of the heap are 18-21'x 3-5'x6-10' respectively. After 24 hours the heap is turned up and settles slightly. The bamboo poles are then carefully withdrawn to create aeration passages. When the internal temperature reaches 60-70°C (after 4-5 days), the ventilation holes are often blocked. The heap is usually turned after 14 days to ensure good mixing of the materials. The compost is normally ready in 8 weeks.

Ecuador on-farm composting: Under this method, the raw materials utilized for compost making are animal manure, crop residues, weeds, agro-industrial wastes, ash, phosphate rock, wood cuttings, top soil from the forest or from an uncultivated or sparingly cultivated area and, freshwater. The raw materials are put in layers in the following sequence in a heap which should 6' x 3-4' x 3-4' (LxWxH).A layer of crop residues (20 cm) followed by a layer of topsoil (2 cm), followed by a layer of manure (5-10 cm), followed by a spreading of ash or phosphate rock (50 g/m²) on the surface, and finally freshwater is sprinkled on the material. These steps are repeated until a height of 3-4'.It is recommended to begin the heap by constructing a lattice of old branches, and to place two or three woodcuttings vertically along the lattice in order to facilitate ventilation. Once a week water should be added to the heap. However, too much water could lead to the leaching of nutrients. After three weeks, the heap must be mixed to ensure that all materials reach the centre. During the process, the temperature rises to 60-70°C, and most weed seeds and pathogens are killed. It may take 2-3 months to prepare the compost in a warm climate and 5-6 months in colder regions.

North Dakota State University hot composting: In this method, compost piles with a height of 6 feet (1.8 m) are raised. If bins are constructed, the dimensions of 5' x5' x6' (Lx Wx H) will yield 150 cubic feet (4.3 cu. m) of compost. This is a respectable volume of compost to be produced in 4-6 weeks. The maximum size of the organic matter pieces should be 6-9 inches (15-23 cm) long.. To keep the aerobic bacterial population high and active, 0.12 kg of an N fertilizer should be added/cubic ft of dry matter and 4-5 holes punched into the centre of the pile.

This is best done in phases or stages as the compost pile is building up. For example, for 150 cubic feet of dry matter, if the pile is built up in three stages (at 2', 4' and 6', 5.7 kg of a N- fertilizer should be added at each stage. The total amount of fertilizer for the entire pile should be about 17-18 kg. In this high

temperature bacterially active system, it is best to turn the composting material every 3-4 days. Once activated, the temperature ranges between 49-71°C. The decomposition is faster in summer (as short as 3-4 weeks) and takes longer in the spring and fall. Once the compost is no longer hot and is an odour-free, crumbling material, it is ready for use.

The Berkeley Rapid Composting Method: This method was developed at the University of California, Berkeley in 1953 and is perhaps the only method which claims to produce quality compost in two weeks. This method was also called as "Two weeks" method because it required several turnings on a fairly rigid schedule. This method can be carried out during the spring, summer or fall. It corrects some of the problems associated with the old type of composting such as nutrient leaching, survival of weed seeds and insects problem.

Vermicomposting

Vermicompost is primarily the excreta of earthworms. The collection of vermicasts along with microbially degraded organic matter is called vermicompost. The term "vermicomposting" refer to the use of earthworms as the living medium for digesting and decomposing organic residues to produce a compost. Earthworms can consume practically all kinds of organic matter and can eat as much as their own body weight per day. Every kg of earthworms feed on 5 kg of waste with 50 to 60% moisture per day. In this way, with the help of earthworms, composting can be carried out with minimum cattle-dung. The excreta "casting" of earthworms are rich in nutrients (N, P, K and Mg) and also in bacterial and actinomycetes population.

The methodology for the preparation of vermicompost is described below from selection of the earthworms to production of vermicompost and saving the worms from predators.

Selection of Suitable Earthworm Species

Out of 3,000 species of earthworms, only a few are known to be used for earthworms for vermicomposting. These are (i) *Eisenia foetida* (ii) *Eudrilus eugeniae* and (iii) *Perionyx excavatus*. The first two are exotic and the third one is indigenous to India. These species are most suited because these are prolific breeders with high multiplication rate, have short life cycles with less mortality and are voracious feeders which excrete high quality vermicasts. They are easy to handle, have lifespan of 1 to 1.5 years, are sturdy and survive very well throughout the year under varying weather conditions. Such species are easily available and economically feasible for vermicomposting. Earthworms are also raised and sold to vermicompost producers, reportedly at around Rs 500/kg.

The biomass production by exotic earthworms like *Eudrilus eugeniae* and *Eisenia foetida* may increase 40 to 90 folds in a period of 3-6 months with adequate space and food. For example, a tank of 60 x 45 x 60 cm can hold of 1,000 to 1,500 adult *Eudrilus eugeniae*, and 3,000-5,000 *Eisenia foetida* or *Perionyx Excavatus*. Their growth rate and reproduction is controlled by their population density. In case of *Eudrilus eugeniae*, earthworms remain small in size and produce less number of cocoons when they are crowded. In comparison, *Perionyx excavatus* and *Eisenia foetida* can withstand the population pressure (density pressure) but *Eudrilus eugeniae* cannot. Thus, frequent harvesting of earthworms is essential to bring down population pressure. Addition of wheat bran, gram husk or gram powder and even neem cake stimulates the reproductive potential of *Eudrilus eugeniae*. Vermicompost is then harvested from the surface and stored in shade. Fresh feeding material is added in the vermibed. After 2-3 days the harvested vermicompost is sieved through 4-5 mm sieves. If the vermicompost contains many cocoons or juveniles or sub-adults, then compost is watered and covered with grass mulch. To collect small worms from vermicompost, small balls of wet cattle-dung are prepared and they are buried at several places in the compost. As markers, small sticks to identify the buried dung can be fixed. It is left for 15 days. After 15 days these balls containing small earthworms juveniles, sub-adults or other escaped cocoons are collected.

Indian Institute of Soil Science has developed some accelerated technologies for rapid decomposition of urban and rural waste. Their applications in soil substantially improve crop yield and soil health. The relevant technologies are as follow:

1. Phospho-sulpho-nitro-compost (PSNC) technology
2. Microbial-enriched compost
3. Rapo-Compost Technology
4. *In-situ* compost technique

1. **Phospho-sulpho-nitro-compost (PSNC) technology:** This method employs both the fortification and the acceleration strategy by using suitable minerals (rock phosphate, pyrites micas etc. and urea nitrogen, so that the end product contains more nutrients per unit weight. To accelerate the decomposition process, microbial cultures (lignocellulolytic microbes such as fungi, bacteria and actinomycetes) were treated into wastes for faster decomposition process and mineralization/solubilization of minerals for improving available plant nutrients in enriched compost, and attained maximum maturity criteria (C:N ratio, lignin/cellulose ratio and CEC/TOC ratio) in 2.5 to 3.5 months (improved method) as compared to the usual six months (farmers practice) in compost prepared from farm residues, vegetable waste and city waste. This mineral enriched compost application @ 5 tonnes ha⁻¹ may supplements about 100 % NPK to soybean and 25 % NPK to succeding wheat crop. Further, it improves soil biological health about 1.5 fold greater than chemical fertilizers. This technology has been demonstrated by IFFCO at different places in India. We have demonstrated in farmers field at Bhopal, Sehore, Vidisha and Raisen districts of Madhya Pradesh. However, we have popularized through ATMA training to farmers and state officials in Bihar, Jharkhand, Chattisgadh, Rajasthan, and Maharashtra.
2. **Microbial-enriched compost:** A consortia of bio-inoculum has been developed at Indian Institute of Soil Science to enhance the decomposition process **to recycle city garbage**. In this methods (pit and windrow method) municipal solid waste compost prepared after 1.5 to 2 months. It improves physical, chemical and biological properties of soils and therefore, better crop productivity.
3. **Rapo-Compost Technology:** A new technology has been developed to speed up the compost time using consortium of Ligno-cellulolytic thermophilic organisms. This technology has been developed by ICAR-IISS in collaboration with ICAR-CIAE and ICAR-NBAIM. This technology is more suitable for recycling of kitchen waste and vegetable wastes. Rapo-compost would prepare quality compost within 1-1.5 months from domestic and vegetable waste. The manurial value improved such as Total N, P, K content to 1.75 %, 0.5% and 1.5% respectively.
4. **In-situ composting technique:** This technology is suitable for direct recycling of post harvest crop residue left over in to filed after mechanical harvester particularly for rice, wheat and sugarcane residue. In this technique, microbial bioinoculum, fresh cow dung slurry, curd and molasses mixed homogeneously and spreaded over the residue and mixed thoroughly with rotavator (2-times). After one month of *in-situ* compost, rice and wheat can grow and after 1.5 months of *in-situ* decomposition, sugarcane may grow in filed. In this process consortia of ligno-cellulolytic microorganisms (4 fungi, 4 bacteria, 4 actinomycetes species identified and cultured at ICAR-IISS, Bhopal) are used to decompose crop residues. For one hectare of rice or wheat about 34 to 38 quintals of post harvest crop residues is left over in the field after combined harvester. These residues can be decomposed systematically with following steps. For *in-situ* decomposition, fresh cow dung about 4000 kg (on dry weight basis) was mixed thoroughly with water. To this slurry about 37 kg urea, 50 kg molasses, 25 kg curd, 1.7 kg mycelial mat (cellulolytic fungi) and 34 L of microbial inoculum (lignocellulolytic bacteria and actinomycetes) were added and spread over the residues. All these residues and ingredients were incorporated into soil by a tractor drawn rotavator. One irrigation was given immediately after mixing these consortia of microbes and other materials. Then, second irrigation was given after 15 days of *in-situ* decomposition.

Economy and impact of *In-situ*-composting

- **Cost:** The cost of *In-situ* residue decomposition including shredding of crop residue by reaper, ingredients (microbial inoculums, molasses, urea, curd etc.), incorporation by rotavator and irrigation (two times) is about Rs. 12000 for one hectare.

- **Crop yield:** The total grain yield of rice and wheat was 36 and 49 quintal hectare in *In-situ* decomposition treated plot which was 4-6 quintal higher than the treatment receiving burning of crop residue and removal of residue.
- **Soil properties:** In a one year study, it was observed that the soil biological activities like soil respiration and dehydrogenase activity was 5-10 % greater in *In-situ* decomposition treated plot as compared to burning and removal of crop residues. The

Organic Matter and Its Significance in Improving Soil Health under IPNS system

Supplementing the chemical fertilizers with organic manures can arrest deterioration in soil health. Thus, ideal way to sustain soil health and crop productivity, integrated plant nutrient supply strategies should be developed for different cropping systems all over the country. Soil organic matter replenishment is the cornerstone to regenerating soil health. Sustenance of soil productivity with continued timely applications of balanced fertilizers with FYM in Inceptisol, Alfisol and Vertisol has clearly been indicated. Plant residues are in the field or returned as compost as much as possible. The necessary removal of organic material in the form of harvested crops is compensated for by growing green manure crops or by amending with compost, which may actually be composed of community food waste, thus tightening the nutrient loop. Imbalanced fertilizer should be avoided or eliminated. To sustain soil biological health different farming systems such as organic-biological farming, biodynamic farming and natural farming should be followed as an alternative agriculture. It influences soil physical, chemical and biological properties and processes. It regulates energy and nutrients for soil biota, aggregate stability, water retention, hydraulic properties, resistance or resilience to compaction, buffering capacity, cation exchange capacity, and formation of soluble and insoluble complexes with metals. The most important biological properties of organic matter are i) its role as a reservoir of metabolizable energy for soil microbial and faunal activities, ii) its effects in stabilizing enzyme activities and iii) its values as a source of plant nutrition through mineralization. Soil organic matter attributes (microbial biomass C and N) are very sensitive to changes in total soil organic matter and could be utilized, based on their relative simple and straightforward methodology, as indicators of soil health. More recently, a greater range of labile soil organic matter attributes such as light fraction of organic matter, particulate organic matter (POM, <53µm), water soluble carbon, acid hydrolysable carbohydrates and potentially mineralizable fraction of carbon are more sensitive to changes in management practices. Little attention has been paid towards labile pools of carbon as compared to total organic carbon in most agricultural soils. Typically, organic matter levels decline rapidly when soil under native vegetation is converted to arable agriculture in the first 10-20 years and then stabilize at a new equilibrium level. In addition labile fraction has a disproportionately large effect on nutrient supplying capacity and structural stability of soil. In agricultural soil, the light fraction typically contains 20-30% C and 5-20% N and 18-22% of total C and 1-16% of total N in the whole soil. Particulate organic matter contains 20-45% of TOC and 13-40% of TN in the whole soil. Particulate organic carbon is the precursor for formation of soil microbial biomass carbon, soluble fraction of carbon, humic and non-humic fraction of carbon in soil and thus it is a key attribute of soil quality. It is the major source of cellular C and energy for the heterotrophic microorganisms. Acid hydrolysable carbohydrate (AHC) (32-37% of TOC) is a labile C fraction and has been found more rapidly in response to changes in management than TOC contents.

The application of compost prepared from either crop residues, municipal solid compost (MSW) or from any other sources increased soil organic matter, N, P and stable aggregates from both amended soils and all labile fraction of carbon. The results also showed a positive response of plant growth and crop productivity due to regular application of compost or manure under IPNS. Further, it was observed that the sources of heavy metals found in all MSW compost such as Cd, Cu, Pb and Zn and there are obvious concerns about such toxic elements entering the food chain through food crops leads to biomagnifications of food chain. Heavy metals are not biodegraded by process of composting, and can become concentrated due to the loss of carbon and water from the compost during microbial respiration. The application of MSW compost in soil can promote changes in soil microbial biomass and activity, mainly due heavy metals content.

Promoting biofertilizers in IPNS with improved technology and extension in India

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Intensive cropping with use of high analysis fertilizers, unscientific usage of fertilizers in an imbalanced way, coupled with an enormous reduction in recycling of organic manures and crop residues is contributing to yield plateaus and reduced factor productivity besides producing adverse effects on soil health. There is thus a renewed emphasis on biological technologies like composting, improving legume BNF inputs, biofertilizers, integrated nutrient management, biopesticides etc. Application of organic manures is required in very high quantities to meet nutrient demand of crops and on the other hand; chemical fertilizers are becoming increasingly expensive for small farmers. On top of this, the use efficiency of applied nutrients from chemical fertilizers is very poor and varies from 30-50% for N, 15-20% P, 8-12% S, 2-5% Zn, 1-2% for Fe and Cu for a range of crops. This contributes to poor economic returns from the expenditure made on chemical fertilizers. Therefore, all efforts must be made to improve fertilizer use efficiency by crops. In view of the above situation, the use of cheap and eco-friendly inputs like biofertilizers is especially important for India and other developing countries where most of the farming will continue to be in the hands of small farmers.

Introduction to Biofertilizers

What are Biofertilizers?

Biofertilizers are preparations of living microorganisms that are useful for promotion of plant growth and soil health through a variety of mechanisms like biological nitrogen fixation, solubilization of insoluble phosphates and other nutrients, oxidation of sulfur, production of growth hormones and combating plant diseases. These include specific strains of bacteria, fungi and blue-green algae. Biofertilizers are useful agricultural inputs because of the following reasons:

1. Eco-friendly way of augmenting nutrient supply and promoting plant growth.
2. Biofertilizers can supplement about 25% of chemical fertilizers
3. Cheap and an efficient source of supplying/mobilizing nutrients.
4. Improves use efficiency of applied chemical fertilizers
5. Promotes plant growth through hormones and vitamin production.
6. Control and suppress soil borne diseases through various mechanisms.
7. Increases crop yields by 10-20%.
8. Improve soil properties and sustains soil fertility.
9. Promotes plant health and improves quality of produce.

By using biofertilizers farmers have most commonly reported earlier seed germination, more greenness, greater tillering and healthy crop stand. Biofertilizers are attractive as a supplement as well as a compliment to chemical fertilizers as they are applied in small quantities, are cheap and when used along with small doses of organic manures and reduced dose of chemical fertilizers, give synergistic benefits on productivity, nutrient use efficiency, crop quality, soil health and disease suppression. Increased emphasis on organic farming, horticulture and commodity crops will require increased supply of quality biofertilizers.

Types of Biofertilizers

The biofertilizers that are widely recommended for crops and produced in significant quantities are:

Rhizobium: Symbiotic nitrogen fixing of legumes which convert atmospheric nitrogen into available forms in the root nodules of legumes, recommended for seed inoculation.

Azotobacter: Non-symbiotic nitrogen fixing bacteria recommended for seed inoculation/ seedling dip of all food, oilseed, vegetable and horticultural crops.

Azospirillum: Associatively symbiotic, nitrogen fixing and plant growth promoting bacteria recommended for rice, maize, sugarcane, millets and vegetables for seed inoculation/ seedling dip.

Phosphate Solubilising Bacteria (PSB): Various strains of *Bacillus* and *Pseudomonas* are known to solubilize insoluble soil phosphates and are recommended for seed and soil inoculation for all crops.

Plant growth promoting rhizobacteria (PGPR): They promote plant growth through a variety of mechanisms like fixation of nitrogen, solubilisation of phosphate, production of growth hormones like auxins and gibberellins, antibiotics, siderophores, ammonia and HCN production and some of them also exhibit ACC deaminase activity. Examples include *Bacillus* and *Pseudomonas*, *Azotobacter*, *Azospirillum* etc. listed above. Even *Rhizobium* is known to exert PGPR action on cereal crops.

Blue green algae (BGA): Non symbiotic nitrogen fixing cyanobacteria, recommended for rice, e.g., *Nostoc*, *Anabaena*, *Aulosira*, *Tolyphothrix* etc.

Azolla: Water fern that has nitrogen fixing *Anabaena* as a micro-symbiont, recommended both as a green manure and as inoculant for rice paddies.

VAM (Vesicular-Arbuscular Mycorrhiza): Fungi which are associated with the roots of most higher plants and helps the plants in mobilizing macro- and micro-nutrients .

In fact there are a number of other microorganisms that are useful as biofertilizers-for example *Thiobacillus* for S oxidation, *Aspergillus* for P solubilization, Silicon and potassium mobilizers, a number of newly reported PGPR like *Burkholderia*, *Acetobacter* all these are not discussed here as they are yet to become very popular from production point of view, the way others mentioned here have become. In fact most of the microorganisms listed in the previous paragraphs are poly-functional nature. Many of them can solubilize phosphorus as well as act as PGPR. Even BGA are known to solubilize phosphate and produce growth promoting hormones. Even BGA are known to solubilize phosphate and produce growth promoting hormones. Therefore a more practical and useful way to classify biofertilizers from the view of application is into three groups:

- 1) *Rhizobium*
- 2) PGPR (*Azotobacter*, *Azospirillum*, *Bacillus*, *Pseudomonas*)
- 3) BGA and *Azolla*.

Technically, those PGPR strains able to supply nutrients to crop plants are included under "Biofertilizers", while the strains responsible for controlling insect pests and diseases are called as "Biocontrol agents".

Biofertilizer Scenario

Biofertilisers are now included in the Fertiliser control order 1985 (amended upto April 2015) which specifies revised standards for ten preparations namely: *Rhizobium*, *Azotobacter*, *Azospirillum*, Phosphate solubilising bacteria, Mycorrhizal biofertilisers, Potassium mobilizing bacteria, Zinc solubilizing bacteria, *Acetobacter*, Carrier based consortia and Liquid Consortia. The global market for inoculants is growing at the rate of 10% per annum had a value of \$440 million in 2012 and is expected to reach about

\$1295 million by 2020 (TransparencyMarketResearch 2014). India and China are promoting the use of inoculants through tax incentives and exemptions, grants to support for the manufacture and distribution of inoculants. Biofertiliser production in India is around 95,000 tonnes per year (in 2015-16) but the potential requirement is much higher. In India among the microbial inoculants, the share of production of *Azotobacter*, *Azospirillum* and *Rhizobium* is 14.4, 12.5 and 8.5% respectively (approx.) The share of P, K and Zn solubilizing bacteria is 30.1, 6.7 and 2.1%, respectively. The share of VAM, *Acetobacter* and NPK consortium is 9.0, 1.2 and 3.1% respectively. There is a need to increase the share of *Rhizobium* in the inoculants production to improve production of pulses. Application of biofertilisers is not a priority for farmers; the main issues are lack of timely availability at sowing time and poor quality in some areas. Other constraints are lack of awareness about biofertilizers due to poor extension efforts and improper application

Biofertilizer Formulations

- 1) *Powders*: This form is used as a seed coating before planting. The smaller the particle size, the better the inoculants will adhere to the seeds. Standard size varies from 0.075 to 0.25 mm and the amount of inoculants used is around 200 to 300 g/ha. These inoculants are most common both in developed and developing countries.
- 2) *Slurries*: This inoculant is based on powder-type inoculants suspended in liquid (usually water). The suspension is directly applied to the furrow or alternatively, the seeds are dipped just prior to sowing.
- 3) *Granular*: These inoculants are applied directly to the furrow together with seeds. Size ranges are from 0.35 to 1.18 mm. Rhizobial inoculants are used at a rate of 5 to 30 kg/ha. These inoculants are popular and have been successfully commercialized since 1975. Bead like forms are synthetic variations of granular forms. These can be in macro sizes (1 to 3 mm in diameter) used as granules form, or in micro size (100 to 200 um) used as a powder for seed coating. The use of each type of inoculants depends upon market availability, cost and the needs of a particular crop under specific environmental conditions. For example, the granular form is better than powder inoculants for rhizobia, under stressful planting conditions, but since more is required, it is costlier.
- 4) *Liquids*: These inoculants use broth cultures or liquid formulations, mainly in water, but also in mineral or organic oils. These seeds are either dipped into inoculants before sowing, or an applicator evenly sprays the liquid inoculants on the seeds. After drying, the seeds are sown. This method ensures even coverage of seeds without interface with seed monitoring system of the planters or inoculums loss when dried. Alternatively the suspension can be sprayed directly into furrow or on seeds before sowing. The furrow inoculation provides a large amount of bacteria to the plant than seed inoculation. These inoculants are currently popular and extensively used in drip irrigation system in several countries.

Carrier Microbial Inoculants (CMI)

Biofertilizer formulation typically consists of establishing the active ingredient (*i.e.*, microorganism) in a suitable carrier together with additives that aid in the stabilization and protection of the microbial cells during storage and transport, and at the target site. The formulation should also be easy to handle and apply so that it is delivered to the target in the most appropriate manner and form, protects the agent from harmful environmental factors and maintains or enhances the activity of the organism in the field. The shelf life of biofertilizer depends on the quality of carrier. The carrier material should have the following characters: non toxic to inoculant bacterial strain, no heat of wetting, good moisture holding capacity, easy to process and free from lump forming materials, easy to sterilize, available in adequate amounts, inexpensive, good adhesion to seeds, good pH buffering capacity and non toxic to host plant and ensures rapid release of bacteria in soil.

Until recent years, all the biofertilizers were prepared as carrier based formulations and peat or lignite are the most widely used carrier material in all these powder formulations. However, these carrier materials are scarce in many tropical areas. Peat is the most frequently used carrier for the rhizobial inoculants industry because it has characteristics such as high water holding capacity and high surface area that support rhizobial growth and survival in large numbers. However, peat is not available in many

countries, especially in the tropics. In tropics, due to unavailability of peat, many alternate carriers including lignite, vermiculite, compost, bentonite, kaolinite, charcoal dust, Perlite and recently cassava wastes have been explored. Most of the evaluated carriers are either naturally abundant or available as waste.

Most of the carrier based inoculants are prone to contamination that can reduce the shelf life of the inoculants. The process of sterilizing the carrier is an imperative but it increases cost of production and labour input. The carrier based biofertilizers generally have short shelf life; improper sterilization of carrier material, unsophisticated handling while mixing the bacterial culture with carriers and packing under unsterile conditions are the major source of contamination and reduce the shelf life of the biofertilizers to less than 6 months. Therefore, many a time, biofertilizer application could not give expected results under the field conditions. The increasing demand for biofertilizers and the awareness among farmers have paved way for the fertilizer manufacturers and new entrepreneurs to get into biofertilizer production.

Carrier based inoculants are usually coated on the seeds. Contact with acidic fertilizers can be harmful to the inoculated biofertilizer organism. Moreover, the solid carrier used in the inoculant requires a significant amount of processing, such as mining, drying, milling and neutralization before it can be used in a commercial production system. Processing carrier requires costly investments in equipment and small production operation is usually not feasible. Carriers are also difficult to process to consistent characteristics, and are not easily used with precision planting equipment. Carrier interferes with the seed monitoring mechanisms of the planters. Addition of adhesives to the inoculants during its application to the seeds or slurry application will improve its adhesion, but that requires additional time and labour for a process that is already labour intensive.

Liquid Microbial Inoculants (LMI)

Liquid biofertiliser is a special formulation containing high number of desired microorganism with high shelf life and zero contamination. Liquid formulations typically are aqueous, oil, or polymer-based products. Polysaccharides such as gums, carboxy-methyl cellulose and polyalcohol derivatives are frequently used to alter the fluid properties of liquid formulations. In fact liquid biofertilisers can overcome many of the biotic and abiotic stress conditions when they are applied to the seed or in the soil. Liquid inoculants may have advantages for smaller scale agricultural systems in the tropics and their local inoculant manufactures. A liquid formulation with good field performance characteristics that uses low cost materials and are easily attainable by small producers could overcome many problems associated with processing solid carriers.

Ease of application of a liquid inoculant either on the seed or *in situ* delivery has enhanced the popularity and use of liquid formulations in several countries in the last decade. Researchers have shown that the performance of liquid rhizobial formulations is comparable to that of peat-based products under field conditions. Liquid inoculant is easily adapted to advance seeding equipment, since it can be sprayed onto the seed as it passes through the seed auger and dries before it travels into the seed bin on the planter. Additives to the liquid broth improve inoculants quality, such as better adhesion to seed, stabilizing the product, binding or inactivating soluble seed coat toxins, and enhancing bacterial survival during storage and after exposure to extreme environmental conditions after inoculation and seed planting. The later issue is perhaps, the most important. Inoculated legume seed are sometimes sown into soil with very high temperatures. High temperature is an important environmental factor that affects rhizobia survival and nitrogen fixation.

Many kinds of polymers have been used as additives for inoculants production because of their ability to limit heat transfer, their good rheological properties and high water activities. These polymers, such as methyl cellulose, gum Arabica, poly vinyl pyrrolidone (PVP) and alginate are normally used adhesive compounds with solid based carriers when they are applied to seed. Polymers that are soluble in liquid inoculants formulations make for convenient batch processing of inoculants and make seed application a simple process for farmers. Polymers are selected based on their properties, such as

solubility in water, non-toxicity and complex chemical nature which prevents microorganisms in the soil from rapidly degrading the polymeric coating.

Singleton et al. (2002) developed different liquid media namely G1, G2, G3, G4, G5, and G6 for *Rhizobium* and extensively studied at different locations of sixteen countries. They reported that media G5 and G6 are superior to other formulations. They found that formulations relying on glycerol as a carbon source met their requirements. In India, liquid inoculants technology has been successfully developed for *Rhizobium*, associative N₂ fixing organisms-*Azospirillum* and phosphate solubilizing bacteria *Bacillus megaterium* var. phosphaticum etc. with long shelf life (Rao et al 2008). Liquid inoculants should be applied at low volumes on seeds as well as to the soil. Such low volume rate application with high bacterial population survival on seed is advantageous for several reasons. Low volume application rates prevent seed bridging (i.e., the clumping of two or more seeds because of excess liquid volume) and it inhibits full coverage of the seed with the inoculants and also inhibits even distribution of the seeds during planting.

The formulated material must remain at acceptable titres for long enough to ensure that at least the minimum number of rhizobia can be applied to seed at the time of sowing. In Canada, seed inoculants must deliver 10³, 10⁴ and 10⁵ rhizobia per seed for small, medium, and large seeds, respectively but some Canadian scientists recommended raising these standards. The results of several experiments showed that G5 formulation and other well formulated liquid inoculants in India (LM3) could support cell survival after inoculation better than most of the commercial solid carrier formulations made available in the market.

Application Methods of Liquid Inoculants

In general, shortly after the bacteria are introduced into the soil, the bacterial population declines progressively. This phenomenon may prevent the build-up of a sufficiently large bacterial population in the rhizosphere to obtain the intended plant response. A major role of inoculant formulation is to provide a suitable microenvironment to prevent the rapid decline of introduced bacteria in the soil. Stress conditions including frequent droughts, lack of irrigation, high salinity and soil erosion etc., may quickly diminish the population of any bacteria introduced into the soil unless precautions are taken to select the proper inoculant and provide irrigation concomitant with inoculation. Inoculation should be timed to coincide with sowing into moist soil or be delivered quickly with irrigation to assure rapid colonization of the target plants as practiced in developed countries. This is often observed with carrier based inoculants whereas this problem can be overcome by inoculating with liquid inoculants.

- Seed Treatment: For one kg of the seed, 5-6 ml of liquid biofertilizer should be mixed with equivalent quantity of 10% starch solution or 10% jaggery solution and coat the mixture uniformly on the seed and expose for drying in shade for 10 minutes before sowing.
- Seedling dip: 250-300 ml of liquid inoculants of *Azospirillum* can be mixed with 70 lit of water and the root portion of the seedlings should be dipped for 10 minutes just before transplanting.
- Soil Application: 250-300 ml of liquid inoculants of each organism can be used for one acre of main field. All the inoculants should be diluted with 10-15 litres of water and then mixed with 200 kg of powdered farm yard manure or vermi-compost or any other compost just before application and incubated overnight. This mixture should be applied at the time of seed sowing/transplantation preferably in the furrows below the seed surface. Immediately after application of microbial inoculants in tropical soils a light irrigation is always preferable.
- Crops with drip irrigation facility: Wherever farmers establish drip irrigation systems in their main field they can use the liquid inoculants of 250-300 ml of each organism per acre in drip tank and release within 10-15 days after transplantation/ sowing. Liquid inoculants are in high demand among Gujarat and Maharashtra farmers especially for drip irrigation under semi-arid climate.

Various methods of application of liquid biofertilizers viz., seed, seedling, soil and drip irrigation were demonstrated and 50% higher grain yields of maize were obtained over solid carrier in Alfisols of Andhra Pradesh. Liquid inoculants of *Rhizobium* and PSB gave 15% extra grain yield over 100% RDF besides saving 50% RDF. Post-sowing application of liquid biofertilizers in black gram compensated for

yields when farmers miss application of solid biofertilizers at sowing. Liquid biofertilizers enhanced the nodulation and growth of pigeonpea even under severe rainfall deficit. Liquid biofertilizers have become popular and farmers in Andhra Pradesh are saving 20-25% of chemical fertilizers and reporting 10-15 % additional yields in their crops. The demand for liquid biofertilizers by the farmers with drip irrigation facility for the crops like cotton, turmeric, sugarcane, sweet orange and pomegranate has increased in Maharashtra.

IPNS with Biofertilizers

Benefits of Biofertilization

The efficacy of various microbial inoculants in increasing the yields and saving nitrogen and phosphorus for pulses, oilseeds, cereals etc., has been convincingly proved in farmers' fields in most agro-eco-zones in India. Mixed biofertilizers (BIOMIX) containing a consortium of N fixers, P solubilisers and PGPR were found to promote the growth of cereals, legumes and oilseeds better (10-25% increase) and saved 25% NP fertilizers in crops. This was convincingly shown in various field experiments and demonstrations conducted by AICRP on BNF and AINP on Soil Biodiversity-Biofertilizers for both aerobic and lowland rice in Tamilnadu; blackgram, chillis, pigeonpea and cotton in high input usage areas in Vertsols of A.P. for groundnut in Junagarh; for cotton, black gram, soybean and pigeonpea in Vertisols of Maharashtra; pearl millet, wheat and mustard in irrigated lands in Hisar and rain fed conditions in Haryana. Biofertilizer packages have been developed for rice in Bihar and North-east India and in Odisha for rice and most other crops. Biofertilizer trials were conducted in AP through 22 DAATT centres. Biofertilizer technology demonstrations in INM package to soybean and wheat farmers was done by IISS, Bhopal.

IPNS in Farmers' Fields

Rice

Azolla or blue green algae can be applied to the rice fields directly. BGA inoculum is applied @ 10 kg/ha in flooded rice. The benefits of Azolla are twofold, firstly it fixes atmospheric nitrogen and secondly it acts as a green manure. For the purpose of biological nitrogen fixation apply Azolla @ of 3-4 kg/10 m²; for the purpose of green manure it is applied @ 10 t/ha. After application sufficient water should be maintained in the field to allow the growth of Azolla. Once it grows fully, it is incorporated into the soil. In Bihar the application of biofertilizers (*Azospirillum*, *Pseudomonas* and BGA), increased the rice yield by 10-20% in small and marginal farmers. Similarly in the North-East region of India in Assam the application of *Azospirillum* resulted in paddy yield of 42 q/ha which was 12.4% greater than with use of chemical fertilizers alone. In the same state, the Jorhat centre of our project developed a simple technique for home-stead multiplication of Azolla by the farmer for their domestic use and found that application @ 2-3 t/bigha resulted in addition of 4-8 kg nitrogen/rice crop (20-40 kg N/ha) giving 10-20 per cent increase in rice yield.

Soybean, Wheat, Pearl millet, Groundnut

The inoculation of *Rhizobium* to soybean in Vertisols increased the yield (by 1.8-2.4 q/ha) and added 15 kg N/ha in soil, which is available to the subsequent wheat crop. In soybean-wheat cropping system the use of biofertilizers in both crops (*Rhizobium* in soybean and *Azotobacter* in wheat), increased the yield of soybean by 10% and wheat by 5% and additionally saved 30 kg chemical nitrogen/ha in wheat. Following this biofertilization practice there was net addition of 15 kg N/ha in soybean and 21 kg N/ha in wheat along with addition of 38 kg/ha nitrogen in soil resulting in total benefit of around 75 kg N/ha. In the districts of Rajgarh and Vidisha in Madhya Pradesh, the application of *Rhizobium* and PSB through integrated plant nutrient management system (chemical fertilizers 50%, 5 t FYM/ha) increased the yield by 18% along with additional N uptake of 34 kg N, 3 kg P and 16 kg K/ha in soybean. In a five year survey of the entire state of Madhya Pradesh, it was found that wherever rhizobial inoculation was practiced by farmers along with FYM and fertilizer application (IPNS) there was best nodulation and grain

yield. This underscored the need to promote awareness for adoption of integrated approach in nutrient management with due emphasis on crop residue/ manure recycling and increased use of good quality rhizobial inoculants to promote yield and BNF of legumes in Madhya Pradesh.

Potassium solubilizing bacteria improved sorghum yields in Andhra Pradesh and also saved 25% K fertilizer. Actinomycetes strains isolated from arid and semi-arid soils improved maize yields in Vertisols of M.P., by 15-30%. In chickpea, yield increases ranged from 20-35%. Formulations of rhizobia and actinomycetes gave high yield increase in chickpea (65%) over uninoculated control. Formulations of actinomycetes (strains A10 and A17) along with PGPR (P3, P10 and P25) significantly improved the yields of wheat and that of soybean and chickpea (with *Rhizobium* added) in Vertisols of Madhya Pradesh. Among zinc solubilizing microbial isolates, *Trichoderma viride* and *Pseudomonas striata* gave best performance in improving yields of soybean, groundnut and cotton, nutrient uptake and soil available zinc in Vertisols of Maharashtra.

With the use of *Azotobacter*, *Azospirillum* and PSB in farmers' fields in Haryana, the grain yield of pearl millet increased by 5% and fodder yield by 6%. Organics have been found to boost the proliferation of *Rhizobium* and enhance nodulation and nitrogen fixation in a number of legumes and oilseeds. In Maharashtra, *Rhizobium* inoculation increased the pod yield by 391 kg ha^{-1} while application of FYM alone @ 5 Mg ha^{-1} increased the yield by 151 kg ha^{-1} . Combined application of FYM and *Rhizobium* increased the yield by 729 kg ha^{-1} . Nodulation, N and P uptake at 60 days as well as *Rhizobium* population in soil were all boosted due to combined application of FYM and *Rhizobium*. This led to the recommendation released at Parbhani "Apply *Rhizobium* inoculants along with FYM @ 5 t/ha". Other studies also showed beneficial influence of organics on legumes. FYM @4t/ha +VAM+ *Rhizobium* had best effect on clusterbean yield and soil microbial properties in an arid soil (Taradar and Rao 2001). In Vertisols, soybean and safflower grain yield increased by 15%, safflower seed oil content and oil yield increased by 1.3% and 4 % due to inoculation. In frontline demonstrations in three soil types soybean seed and groundnut pod yield increased by 27% and 22% respectively In Gujarat, the inoculation of groundnut seeds with *Rhizobium* and PSB increased the yield by 10-12% along with additional increase in 6-10% N and 4-8% P. Fluorescent pseudomonads inoculum for control of stem rot of groundnut improved pod yields in Gujarat by 7-20%.

Mother–baby field trials, involving on-farm participation to introduce and test technology options, was used to evaluate the best possible nutrient management technologies in a soybean–wheat system on Vertisols deficient in N, P, S and Zn in Rajgarh, Madhya Pradesh, India (Reddy et al. 2013). Two sets of >90 baby trials conducted by farmers in 2007–2008 and 2009–2010 in 10 villages of Bhopal, Raisen and Vidisha districts of Madhya Pradesh showed the benefits of this INM technology. Balanced fertilization (BF) with recommended rates (kg ha^{-1}) of 25 N, 26 P, 17 K, 20 S, and 5 Zn gave ca. 26% increase in soybean seed yield over the farmers' practice (FP). Integrated Nutrient Management (INM) (50 % of the recommended inorganic fertilizer + 5 t FYM ha^{-1} + seed inoculation with *Rhizobium*) was superior and increased the seed yield by ca. 48 % over the farmers' practice (FP).

Fruits, Vegetables, other commercial crops

Biofertilizers have so far been seen only as a means of augmenting nutrients through biological nitrogen fixation, phosphorous solubilization, etc. But recent researches reveal that they can improve fertilizer use efficiency and can be exploited for this purpose. Vegetables have a short growing cycle and are an essential part of human diet consumed daily. Balanced nutrients are required for high production of vegetables; therefore there is a need for the integrated use of different plant nutrients. In Orissa, under the All India Network Project on Biofertilizers, biofertilizers like *Azotobacter*, *Azospirillum*, *Rhizobium* (for leguminous vegetables) and PSB were used for cultivation of different vegetables either singly or along with FYM or vermicompost application to soil. The microbial inoculum was prepared by enrichment of FYM/vermicompost with different microorganisms (*Azotobacter*, *Azospirillum*, and PSB) and incubation

which increases the microbial counts 10-15 fold. The effects were seen on different vegetables (beans, cowpea, okra, chilli, radish, mustard, potato, carrot, turmeric, brinjal, tomato, ginger, yam etc) resulting in yield increase by 8-12% for above ground and 25-30% for below ground vegetables. Bioinoculation of vegetables saved N and P fertilizer dose by 20-25%, improved the nutrient use efficiency by 12-36% for N, 18-28% for P, 9-15% for K and 16-18% for S. The use of biofertilizers also improved the quality of produce-for example in tomato anti-oxidants like lycopene increased by 13% and Vitamin C by 27 %. Curcumin content of turmeric increased by 10% in farmer field produce. So biofertilizers have an important role in improving the nutritional security of farmers.

Inoculation of *Azospirillum* and *Gluconacetobacter* increased the grain yield (30%) and juice and ethanol yield (17%) of sweet sorgum in Vertisols of Maharashtra. Field demonstrations of PGPR *Bacillus licheniformis* controlled white root rot disease of apples and increased yields by 40% in Himachal Pradesh. Work on PGPR for improving yields of cherry, apricot, seabuckthorn and medicinal plants in progress. Biofertilizer package for cauliflower increased yields by 25-30% in Himachal Pradesh and saved 25% NP fertilizers.

Kodo, Kutki and Niger

The tribal areas of Dindori district of M.P have mainly shallow, skeletal soils. In this area agriculture is mainly rain fed. The livelihood of these farmers is based on cultivation of minor millets like Kodo, Kutki and oil seeds like Niger (Ramtil). Here the usage of chemical fertilizers and other agricultural chemicals is meagre. Hence the use of biofertilizer technology is extremely profitable. Biofertilization with *Azotobacter*, *Azospirillum* and PSB gave yield increases by 5-10% over farmers' practice where no fertilizers are being used. IPNS treatment resulted in substantial yield increase ranging from 100-230% over farmers' practice.

Biofertilizers in Eastern India

In eastern India mycostraw enriched with *Pseudomonas*, *Azospirillum*, Cyanobacteria gave rice yield increase of 10-20% in resource poor and 6-10% increase in resource rich farmers in Bihar. Lentil yields increased by 10-20% due to *Rhizobium* inoculation. Arbuscular mycorrhizal fungi (AMF) inoculum for upland rice in Jharkhand improved rice yields by 7-20%. In Odisha in tribal areas of Kalahandi biofertilizers improved cotton unit yield by 30%. The average benefit was Rs 11,520 ha⁻¹. Cultivation of vegetables (cabbage, cauliflower, broccoli, capsicum) with bioinoculation increased yields by 10-20%. In Jute-rice-green gram system in Odisha, jute yield increased by 19% due to biofertilization over soil test dose, in rice by 8% and in green gram by 12%. NPK recovery increased from 62.0 to 74.0% in STD + BF (extra nutrient uptake of 42 kg/ha). In Jute in Assam, application of biofertilizers consortia (*Azospirillum*, *Azotobacter* and PSB) as seed treatment decreased the consumption of chemical fertilizers by 50%. Application of microbially enriched compost @2t/ha gave best yields and capsaicin content of hot chilli in NE India. Microbially enriched compost (5t/ha) with biofertilizer or green manure with biofertilizer or *Azolla* @0.5t/ha with biofertilizer gave highest rice grain yield. Application of K along with enriched compost saved 25-50% dose of NP in NE India. In Mandla and Chhindwara districts of Madhya Pradesh., inoculation gave additional yield of 10-20% in pulse crops and 15% in soybean and maize. Livelihood improvement of a small farmer owing 1ha land in coastal acid soil of Odisha was demonstrated by cultivation of vegetables, cereals, pulses, oilseeds, resulting in an additional income of Rs 8300/ha. In term of cost inputs B: C ratio of biofertilizers was 14:1 and overall B:C ratio of cultivation increased from 2.1: 1 (without usage) to 2.5:1 due to biofertilizer usage. Use of biofertilizers in field demonstrations in upland crops (rice and pigeon pea) in Jharkhand gave 10-30% yield increase. *Azolla* cultivation was demonstrated to 10KVK's in Assam.

IPNS in Tribal Areas

Biofertilizers were evaluated in tribal areas of Odisha, M.P., M.P., and Kerala for livelihood improvement. During 2014-16, 60 field demonstrations were carried out on soybean, maize, wheat, chickpea, pea, lentil and rice in tribal farmers' fields in Mandla, Chhindwara, Jabalpur, Dindori, and

Balaghat districts of Madhya Pradesh with the application of recommended dose of fertilizers along with biofertilizers leading to significant yield gains over farmers' practice. 210 field demonstrations on biofertilizers were carried out among tribal farmers in Kalahandi and Rayagada districts in the state of Odisha growing vegetables, pulses, cereals, oilseeds and fibre crops. There was significant economic benefit with farmers earning Rs.20/- per rupee investment on compost, biofertilizer and lime. The TSP programme besides generating additional income, also helped in generating year round employment for neighbours and thus checking migration of labourers out of the state. Creation of vermicompost pits out of the TSP fund helped preparation of good quality compost throughout the year, kept the rural environment clean and hygienic and helped save at least 25 per cent of the cost incurred on costly chemical fertilizers. A consortium of biofertilizers consisting of *Azospirillum lipoferum*, *Azotobacter chroococcum* and Plant Growth Promoting Rhizobacteria (PGPR Mix I) were supplied to 125 farmers in ten tribal settlements in Wayanad, Kerala for ginger, pepper and vegetable cultivation. In Attapady, Palghat, Kerala PGPR Mix I was distributed to 600 farmers engaged in the cultivation of vegetables, pulses, banana, sorghum, groundnut, ragi etc. Over 400 farmers and 50 extension officers were trained on biofertilizer usage at both places.

Promotion of Biofertilizers

Benefits of Regular Inoculation

Surveys on rhizobial populations in the AICRP on BNF for the major grain legumes have shown populations to be well below the threshold in all areas and below 100 cells/g. (Raverkar et al 2005) due to the extremely high soil temperature and drying of surface soil layers in summer. Recent studies on diversity of rhizobial populations in the AINP on Biofertilizers have also thrown up challenging issues for rhizobial strain selection strategies for major pulse growing regions in the country. In a five year survey of the entire state of Madhya Pradesh, it was found that wherever rhizobial inoculation was practiced by farmers along with FYM and fertilizer application (IPNS) there was best nodulation and grain yield (Rawat et al 2008). This underscored the need to promote awareness for adoption of integrated approach in nutrient management along with use of good quality rhizobial inoculants to promote soybean yield and BNF .

Production and Use of Biofertilizers

Adequate precautions need to be taken in the use of biofertilizers. Since biofertilizers contain live cells, care should be taken during their transportation and storage. They should be kept in a cold place and not exposed to sunlight. Legume cultures are crop-specific and they must be used for the crop for which they are meant. If they are to be used under adverse soil conditions, appropriate remedial measures like liming and use of gypsum should accompany their application to soil. At present about 95,000 tonnes of biofertilizers are produced in India. In majority the carrier is a solid support like lignite or charcoal. Strictly sterile conditions are required to be maintained in its production at all stages to obtain a good quality product alongwith proper storage conditions to ensure acceptable cell count ($> 5 \times 10^7$ cells/g) at the end of six months expiry period. Liquid biofertilizers with added cell protectants to improve survival of bacteria have been shown to have higher shelf life upto one year. The use of microbial inoculants is now finding increasing acceptance in many areas and farming situations, particularly in organic farming pockets. But there are serious concerns about the poor quality of inoculants from many production units who employ unsterile carriers and unhygienic production methods resulting in high level of contaminants.

Successful production of bacterial inoculants needs to be associated with an effective, regulatory quality control programme. Most countries have some form of quality control which may be supported by appropriate legislation or may be voluntary on the part of the inoculant manufacturers. The quality control programmes deal mainly with the quality of the strains in the inoculants and their numbers as well as the numbers of contaminating microorganisms. The whole question of inoculants and their use starts with quality. If the quality is poor, then everything else is irrelevant. The testing of liquid inoculants for quality aspects is easy and quick when compared to carrier based inoculants. In general contaminants levels will be zero at the time of packing. The Bureau of Indian Standards has produced quality standards for most

inoculants. The Govt. of India has included biofertilizers in the Fertilizer Control Order making it mandatory for manufacturers to register themselves with state governments. A quality control mechanism has been put in place and responsibility entrusted to the National Centre on Organic Farming of the Government of India.

Adoption of biofertilizers by farmers

With proper usage, farmers have reported more vigorous crops (greenness), bolder grains and better yields. Soil application is preferred for rice by most farmers. Adoption is easy in vegetable growing as it involves only dipping of seedlings and success is better since FYM is invariably applied and good irrigation regimes are maintained. This invariably led to improvement of the quality of the produce and better nutrient use efficiency. The B/C ratio of Biofertilizers is on the average ~15 and can even be as high as 80. Adoption has been good when there is good investment by state in Microbiology teaching and Research as for example in Tamilnadu. Crucial role of TV/ Radio, sale of BF packets through seed depots, advertisement through posters etc needs to be recognized. Adoption has been good wherever the manufacturer is doing "niche marketing". Success has also been obtained in areas where organic residues are available for recycling through horticultural shrubs, trees etc. Adoption of biofertilizers has been better in Southern and Western India. Success stories include widespread usage of *Azospirillum* for rice in Tamilnadu, *Rhizobium* for soybean in Madhya Pradesh, and *Pseudomonas* and *Bacillus* (referred as PSB-phosphate solubilizing bacteria-although the action is more akin to a PGPR effect) in many areas.

There are some constraints in adoption of biofertilizers which has led to their being adopted on a scale that is desired. Application of biofertilizers is not a priority for most farmers. In a survey by AICRP-BNF (Rao 2000, detailed report in Ilamurugu et al 2008), problems cited by farmers in Tamilnadu are: Lack of timely availability of inoculants at sowing time and supply of expired packets. Bottlenecks in wide spread adoption of inoculants by farmers include poor quality due to low count, contaminants etc., lack of awareness about BF's due to poor extension efforts and improper application methods (simply mixing powder with seeds) among others. Insufficient extension efforts have contributed to poor diffusion of BF technology. Mushroom growth of production units set up by low and medium investors solely with profit motives, not employing qualified microbiologists, using unsterile carriers with hardly any quality control have mainly contributed to the poor quality. The very low cost of inoculants adds to the problem of maintaining high quality. Quality control is thus largely voluntary. On the other hand the main constraints expressed by manufacturers are: unattractive carrier material, low shelf-life, lack of proper storage facilities, loss of quality on transportation, poor marketing, high risk and less profit discourages dealers, market captured by unwanted companies, mushroom growth of profiteers.

Successful Solutions and Way forward

There are many success stories of biofertiliser usage all over India e.g., *Azospirillum* for rice in Tamilnadu, *Rhizobium* for soybean and phosphate solubilizing bacteria (PSB) all over the country. Biofertiliser adoption is easy in vegetable growing and very successful since farm yard manure is invariably applied and good irrigation regimes are maintained. This leads to improvement of the quality and shelf life of the produce, and improved nutrient use efficiency. These success stories need to be replicated more widely. The production of biofertilisers and usage is more in southern and western India but is now also picking up in eastern India. The main issues pertain to selecting the best suited and most efficient microbial strains for a crop/soil/region; use of certified mother cultures supplied by R& D laboratories for industrial production, using only sterile methods of production and maintaining high quality at all stages - production, storage and till its supply to the farmer. It should be mandatory for the industry to disclose details of strain used and its source in the registration certificates and inoculant literature.

Rhizobia rapidly die off in surface soil layers due to heat and desiccation. Improving the pulses production thus requires inoculation each year and greater production of quality rhizobial inoculants. The share of rhizobia in biofertiliser production is only 15%. To cover the entire legume acreage (including soybean and groundnut) the production of rhizobia needs to be increased 3-4 fold to at least 20-25,000 tonnes. To cover all crops, including horticultural and plantation crops with reasonable rate of application,

total biofertilizer production in India needs to be increased 8-10 fold from the current 50,000 tonnes to about 0.4-0.5 million tonnes each year. This requires major policy directives to boost infrastructure and encourage the private sector. Allowing market force mechanisms for maintaining quality through creation of brand equity by reputed players will give a fillip to the industry.

Liquid biofertilizers with added cell protectants to enhance the shelf life have shown good agronomic performance (Trimurtulu and Rao 2014) has already been discussed. Addition of small amounts of humic acid has been shown to promote survival of bacteria in solid carriers. Microencapsulation through immobilization of microbial cells or their consortia in biodegradable polymers to protect them against dryness and other environmental stresses during storage needs more research. Viability of custom coating of seeds with nutrients, fungicides and biofertilisers is uncertain due to infrastructure problems of cold storage and other logistical difficulties. An ecological approach based on bio-films are showing promising effects and research is underway on natural clay based nano-biofertilisers. Production of mycorrhiza needs to be stepped including production in synthetic or semi-synthetic media. The use of microbial consortia having two or more beneficial organisms is showing promising results. Extensive field experiments conducted in farmer fields under the ICAR-All India Network Project on Soil Biodiversity-Biofertilizers in eastern India have demonstrated the benefits of microbial consortia. For example in Bihar for rice, use of *Azospirillum*, blue green algae and *Pseudomonas* has been shown to confer differential benefits at different plant growth stages. The use of carrier based biofertiliser inoculants pre-incubated in FYM or microbially enriched compost have both shown excellent responses in all crops, particularly vegetables in Odisha and Assam respectively. Other inoculants used though in lesser quantities are blue green algae and *Azolla* there is a great potential to step up their production through de-centralized units using local strains - many *Krishi Vigyan Kendras* of ICAR are already producing them and need to be supported vigorously. Research is under-way on newer plant growth promoting inoculants like Actinomycetes and *Arthrobacter* which are showing promise on a wide variety of crops. *Methylobacterium* has shown promise in imparting stress resistance to rice under drought conditions. In diversification of usage, improvement in yield of fibre crops like jute and cotton, particularly on quality aspects; floriculture-size and shelf life of flowers; high value crops like hot chillis etc., are recent results that need to be further exploited widely by scaling-up.

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Significance of greenhouse gas cycling towards nutrient transformation in agricultural soil ecosystem

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Introduction

The three major GHGs are CO₂, CH₄, and N₂O. However, CH₄ and N₂O are more important greenhouse gases than CO₂ because of their global warming potential. The ability of CH₄ and N₂O molecules to absorb infrared radiation makes these gases 20–30 and 200–300, respectively, more effective than CO₂ as a greenhouse gas, resulting in significant contribution to the radiative forcing of the atmosphere and associated global climate change. Microbes are involved in carbon, nitrogen, phosphorous and other elemental cycles. Microorganisms are also responsible for both the production and consumption of greenhouse gases. Soil microbes thus exhibit both positive and negative feedback to atmospheric GHGs. These microbial activities are also influenced by the climatic factors. The reason for this microbial response to climate change is due to the complex interaction of microbes with higher organisms and environment. This complex interaction is not clearly known making it difficult to accurately predict the response of microbes to climate change. It has been noted that human activities have increased the production of greenhouse gases originating from microbial community. The chapter aims to provide information on (1) the microbial processes regulating cycling of the CH₄ and N₂O in soil and (2) microbial strategies to mitigate GHG emission from agricultural soils.

Flux and feedback cycling of CH₄

The production of CH₄ by anaerobic methanogens includes reduction of methanol, CO₂ and cleavage of acetate, as well as biosynthesis of methylated compounds (Angel et al., 2012). Methanogenic archaea are two types: acetoclastic and hydrogenotrophic. These two groups of methanogens play a vital role for all biogenically produced CH₄ in anoxic habitats. Acetate is used as C source by the acetoclastic methanogenic archaea. These groups are represented as Methanosaetaceae and Methanosaetaceae. Species belonging to Methanosaetaceae are abundant in paddy soil when acetate concentration is low, while Methanosaetaceae are dominant at higher acetate concentration (Eller et al., 2005). Hydrogenotrophic methanogens use H₂ and CO₂ for methanogenesis. The hydrogenotrophic methanogens are Methanocellales, Methanomicrobiales, Methanosaetaceae, and Methanobacteriales. In wetlands CH₄ formation from H₂/CO₂ is much larger (up to 67%) than from acetate (33%) (Conrad, 1999).

Methane is produced under anaerobic conditions by the methanogens, but the net amount of CH₄ reaching the atmosphere is influenced by many abiotic factors including soil temperature, pH, nutrient content and moisture. Plants regulate the flux of CH₄ from wetlands by different processes. Plants can stimulate CH₄ emissions by providing carbon substrates to the methanogens. These C compounds originate from plants as root exudates. Plants also help in the transport of CH₄ from soil to atmosphere by acting as a conduit. Plants create oxidized condition in the rhizosphere that can influence CH₄ oxidation. The relative significance of these processes varies among plant species.

Amendment of rice straw to flooded paddy soil improves soil structure and soil organic carbon in the long term (Zhang et al., 2013). However, such practice potentially increases CH₄ emission from soil into the atmosphere (Yuan et al., 2014a). The decomposed organic matter acts as an electron source to reduce O₂, NO₃, Fe³⁺, Mn⁴⁺, SO₄²⁻ and CO₂ sequentially in the anaerobic soils. Presence of electron acceptors other than CO₂ i.e O₂, NO₃, Fe³⁺, Mn⁴⁺, SO₄²⁻ inhibits methanogenesis (Rissanen et al., 2016). Methanogens respond differently to the incorporated organic residues. The abundance of the methanogenic communities increases during anoxic decomposition of rice straw (Yuan et al., 2014). It has

been reported that rice straw incorporation into soil selectively enhances population of Methanosaericae and Methanobacteriales, and decreases methanogens belonging to rice cluster I (RC-I) and Methanomicrobiales (Hernández et al., 2017).

Methane oxidation

It is estimated that globally CH_4 consumption is about 30 Tg yr^{-1} (Rice et al., 2016). Although CH_4 consumption occurs in a wide variety of upland soils, the pristine forest soils have been identified as the most promising sinks for atmospheric CH_4 (Lohila et al., 2016; Tupek et al., 2014). Various agricultural factors regulate CH_4 oxidation. Some of these factors are soil compaction, pH and fertilizer application (Ball, 2013), abandonment of agricultural land or even converting it to forest can potentially increase the atmospheric CH_4 uptake to some extent.

The first step of CH_4 oxidation is catalyzed by the enzyme methane monooxygenase (MMO) (Fig 2) (Lee et al., 2013). This enzyme occurs as a membrane-bound particulate methane monooxygenase (pMMO) and (2) a cytoplasmic soluble methane monooxygenase (sMMO) (Ho et al., 2013). Most of the methanotrophs (except *Methylocella*), possess pMMO. This enzyme is constituted of three membrane based polypeptides encoded by *pmoC*, *pmoA* and *pmoB* (Kang and Lee, 2016). Certain Type II methanotrophs (*Methylosinus*, *Methylocystis*), Type I methanotrophs (*Methylomonas*, *Methylomicrobium*) and type X (*Methylococcus capsulata*) possess sMMO in addition to pMMO (Cantera et al., 2016). The enzyme from the *Methylosinus*, *Methylocystis* and *Methylococcus* has been thoroughly studied. The nucleotide sequence of the sMMO gene is constituted of *mmoX*, *mmoY*, *mmoB*, *mmoZ*, *mmoC* and *mmoD* (Strand et al., 2013). The DNA sequences of this cluster are highly conserved. The *pmoA* gene encodes a 26-kDa subunit that harbors the active site for pMMO. The *mmoX* gene encodes for α -subunit of the sMMO hydroxylase. These genes are used as genetic markers to identify enzymes of various methanotrophs. Methanol dehydrogenase (MDH) is the second enzyme involved in methane oxidation. It is present in all methylotrophs including methane and methanol users. This enzyme is encoded by *mxaF* gene and is an appropriate marker for identifying methanotrophs possessing MDH activity (Haque et al., 2016).

Fe Redox cycling can modulate CH_4 consumption in soil

CH_4 . In a study, (Mohanty et al., 2017) two soil types (alluvial and vertisol) were simulated to undergo microbial Fe reduction and aerobic oxidation repeatedly by natural wetting-drying cycle. Potential iron reduction rate k ($\mu\text{M Fe}^{2+}$ produced g^{-1} soil d^{-1}) increased from 1.26 to 2.16 in vertisol and 1.95 to 3.05 in alluvial soil. Potential iron oxidation in both soils increased with repeated flooding and drying. The iron reduction-oxidation significantly ($p < 0.05$) stimulated CH_4 oxidation rate. The high affinity CH_4 oxidation rate ($\mu\text{g CH}_4$ consumed per g soil per day) increased from 0.03 to 0.19. Low affinity CH_4 oxidation rate increased from 0.05 to 0.47 in vertisol. X ray diffraction (XRD) revealed that diffraction intensity of Fe minerals (magnetite and goethite) decreased over iron reduction oxidation cycle. Real time PCR quantification of methanotrophs (*pmoA* gene) confirmed that iron reduction oxidation cycle stimulated ($p < 0.05$) methanotroph abundance. The study highlights that iron reduction-oxidation cycles can significantly enhance CH_4 oxidation in tropical soils (Mohanty et al., 2017). Previously, in a nitrate dependent Fe reduction-oxidation cycling study, it was found that highly reactive, amorphous Fe^{3+} oxide phases were formed (Fortin and Langley, 2005). Surface area of Fe minerals is the gross indicator of the relative abundance of Fe^{3+} oxide surface available for microbial attachment (Tobler et al., 2007). This apparent dependence on surface area provides a functional explanation for the major differences in the microbial activity on various types of Fe^{3+} oxides (Roden and Zachara, 1996). A high surface area of Fe minerals may change the soil environment to more aerobic and nutrient rich supporting the microbial activity (Li et al., 2013). It is hypothesized that low crystalline Fe minerals act as micro-environments for bacterial activity. Probably, these altered properties of Fe minerals results after iron reduction-oxidation cycling favored methanotrophs and stimulated CH_4 oxidation.

Nitrous oxide (N_2O) cycling in soil

N_2O is the most potent one. In terrestrial ecosystem it is produced from both natural and anthropogenic sources. Many other sources are there which produce significant amount of N_2O , but they are not clearly understood and also difficult to measure. Therefore, there is a general agreement that the atmospheric sources and sinks of N_2O are difficult to balance. Nitrous oxide is a long-lived trace gas, with its average mixing ratio of 330 ppbv (Arevalo-Martinez et al., 2013). The concentration of atmospheric N_2O has increased by 19% since pre-industrial period but has increased by 0.77 ppb yr^{-1} during 2000–2009. It is a potential GHG with a 100-year global warming potential of 298 times higher than CO_2 . It contributes 6.24% to the overall global climate change (Huang et al., 2013). The dominant sources of N_2O are the microbial processes in soils, sediments and water bodies. N_2O emission from agricultural use of N fertilizer and manure management accounts for 4.3–5.8 Tg N_2O-N yr^{-1} . Its emission from natural soils ranges from 6–7 Tg N_2O-N yr^{-1} . Thus N_2O represents 56–70% of all global N_2O sources (Reay et al., 2012).

Nitrous oxide production from nitrification and denitrification

Soil N_2O emission varies spatio-temporally and is also characterized by hot spots and timings. N_2O fluxes from soil are not only restricted to the specific sites of N fertilization, but also owes to the volatilization, leaching, atmospheric deposition and erosion processes. In natural ecosystem N fertilization creates new hot spots for N_2O emissions. However, it is challenging to integrate N_2O flux originating from nitrification and/or denitrification which often occur in close vicinity. Because a substantial part of the NO_3^- formed by nitrification diffuse into anaerobic zone where it is denitrified into N_2 . N_2O production occurs from both nitrification and denitrification (Fig 3). N_2O from nitrification and denitrification contribute approximately 70 % to the global N_2O budget (Butterbach-Bahl et al., 2013).

The mechanism of N_2O production by nitrification is not clearly known. Three main hypotheses have been proposed:

1. During nitrification a constant proportion of NH_4^+ is converted to N_2O . This results into formation of various intermediate products. N_2O is produced from an intermediate product HNO produced during the oxidation of NH_2OH to NO_2^- . HNO is further oxidized to an unknown compound, which is subsequently oxidized to NO_2^- .
2. N_2O is produced when NO_2^- is reduced by accepting electron. Mostly, it occurs during NH_4^+ oxidation when O_2 pressure is low. Partial pressure of O_2 in soil varies with soil moisture.
3. N_2O is also produced during the partial oxidation of NH_4^+ into NO_2^- . When NO_2^- is diffused into anaerobic regions of soil, it is denitrified to N_2O .

Both ammonia oxidizers and methanotrophs produce N_2O during the oxidation of NH_2OH to NO_2^- . Certain ammonia-oxidizers reduce NO_2^- to N_2O and then to N_2 under anoxic condition. This process is termed as nitrifier-denitrification. Under strict anaerobiosis N_2O is also produced by denitrifying organisms.

N_2O emission from soil is influenced by agricultural practices, climatic conditions and soil properties. Soil factors include soil moisture and temperature, aeration, ammonium, and nitrate concentration, and pH. Soil moisture content is one of the predominant factors regulating N_2O emission from soils. However, it has been observed that alteration in the soil water content due to wetting events such as irrigation and rainfall can stimulate nitrification and denitrification, and promote N_2O production. N_2O emission is highly correlated with water filled pore space (WFPS). In an intensively managed calcareous Fluvo-aquic soil, highest N_2O emission occurred under 70% WFPS originating from both nitrification (35–53%) and denitrification (44–58%) (Huang et al., 2014). The favorable conditions for N_2O production from nitrification occur within the range of 30–70% WFPS (Hu et al., 2015), whereas denitrification dominates N_2O production in wet soils with >80–90% WFPS (Huang et al., 2014).

Mitigation of N₂O emission from soil

Soil biochar amendment has been described as a promising tool to mitigate N₂O emission from agricultural soil. Many studies link the N₂O emission mitigation and the abundance and activity of N₂O-reducing microorganisms in biochar-amended soils (Cayuela et al., 2014; Harter et al., 2014; Van Zwieten et al., 2015).

Table 1: Various nitrogen transforming microbial processes under oxic and an-aoxic ecosystem. N₂O is produced by both aerobic nitrifiers and anaerobic denitrifiers.

N cycling processes	Oxic / Anoxic	N molecules formed during microbial metabolism									
		R-NH ₂	NH ₄	NH ₂ OH	N ₂ O	NO	NO ₂	NO ₃	NO ₂ ⁿ	NO	N ₂ O
Heterotrophic nitrification	Oxic	x	x	x	x	x	x	x			
Autotrophic NH ₄ oxidation	Oxic		x	x	x	x	x	x			
Autotrophic NO ₂ oxidation	Oxic						x	x			
Coupled nitrification - denitrification	Anoxic						x	x	x	x	x
Nitrifier denitrification	Anoxic					x			x	x	x
Anoxic denitrification	Anoxic						x	x	x	x	x
Denitrification with NO	Anoxic		x						x	x	x
Denitrification with N ₂ O	Anoxic	x							x	x	x

Biochar amendment shapes the N₂O reductase gene (*nosZ*) carrying soil microbial community. In a study, the diversity of bacterial 16S rRNA gene and *nosZ* genes was explored under the influence of biochar (Harter et al., 2014). Soil with biochar significantly altered the 16S rRNA gene-based community composition. Biochar amendment developed distinct bacterial community capable of N₂O reduction containing *nosZ* gene. The sequences of the enriched bacterial population were closely related to *nosZ* genes of *Pseudomonas stutzeri* and *Pedobacter saltans*. Further studies are needed to establish the molecular basis of *nosZ* gene expression in soil amended with biochar.

Conclusive remarks

To regulate GHG emission from agriculture, it is important to understand the microbial processes governing the flux and feedback of GHGs. CH₄ and N₂O are the two most important GHG emitted from agricultural soil. Several microbial processes are involved in GHG cycling like methanogenesis, methane oxidation, nitrification and denitrification. CH₄ can be mitigated by promoting methanotrophs through soil biogeochemical process. One such intervention is alternate flooding and drying and Fe cycling. N₂O emission can be mitigated by exploring the microbial groups like N fixers with N₂O reductase gene. It is concluded that apart from agricultural management strategies GHG emission from agriculture can be mitigated through biogeochemical processes and by using microbial groups with GHG metabolizing genes.

Practical/Experimental/Field visit section



Mridaparikshak: A mini lab for soil health assessment

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Introduction

Good soil health is the key to the sustainable agriculture and farmers' income. Good soil health can only be maintained with the periodic assessment of soil health parameters. There are 140 million farmers' holdings in India which would require testing of 47 million soil samples in one year, if samples are tested periodically at an interval of 3 years. This is not possible with 1600 traditional soil testing laboratories, with only 600 laboratories with micronutrient testing facility in India. The existing infrastructure of traditional laboratories could estimate only 6 million soil samples for all the essential soil health parameters in one year. Creation of new laboratories would require investment of thousands of crores. Mridaparikshak mini lab has made this possible. Mridaparikshak costing only Rs. 86000/ is far cheaper and economical when compared to traditional laboratory which costs around one crore for its creation.



Features

- Mridaparikshak is a digital, mobile, quantitative, rapid, affordable and easy to operate mini laboratory, for the estimation of soil health parameters, fertilizer recommendations, and generation of soil health cards.
- It gives quantitative results of the soil health parameters that can be disseminated on real time basis to the farmers' mobile through Short Message Service (SMS).
- The results include, in addition to soil test parameters, the advisory on nutrient recommendations, specific to crop and soil.
- The results can also be stored in memory and the output can be saved in external storage devise.
- Subsequently, a soil health card can be generated which can be sent to farmers either electronically or by post in the form of hard print.
- Mridaparikshak is protected vide patent application No. 2522/DEL/2015.

Impact

Mridaparikshak mini lab is a technology of recent origin. The first version of Mridaparikshak was launched in Indian market in August, 2015. Subsequently, the technology has been upgraded to include all the essential parameters required for making the soil health card as per the Govt. Soil Health Card Scheme (SHC). In a short span of two years, 8785 Mridaparikshak units have been sold in Indian market and 3.34 million soil samples have been analysed and millions of soil health cards have been prepared (on all India basis, around 14% of the total SHC are prepared by Mridaparikshak during 2016-17). In years to come this technology is expected to increase its share significantly in the area of soil health assessment and preparation of soil health cards. Mridaparikshak mini lab has been procured by almost the

all the *Krishi Vigyan Kendras*, several state department of agricultural laboratories, NGOs, Public Sector Organizations and others.

Components

Mridaparikshak comprises of a manual (giving details on how to use Mridaparikshak); equipments (Smart Soil Pro: an instrument that measures available forms of nutrients and prescribes fertilizer nutrient doses, shaker, weighing balance, and heater); reagent bottles filled with chemicals; glass-wares and plastic-wares; filter papers; sieves; other accessories that include poly-bags for soil sample storage, tissue papers, rods for stirring, gloves, goggles, notebook for recording the soil data, and distilled water (single and double separately).

Working

Mridaparikshak can determine available form of nutrients such as nitrogen (N), phosphorus (P), potassium (K), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and boron (B). It can additionally provide status of soil pH, soil electrical conductivity (EC) and organic carbon. In addition, it can also assess special soil conditions such as alkalinity, acidity and calcareousness and prescribe the rates of amendments. Mridaparikshak can also prescribe fertilizer doses for primary nutrient namely N, P, and K for targeted yields of different crops grown in different soils. It can also prescribe doses of secondary and micronutrient fertilizers namely S, Zn, B, Fe, Mn and B.

Benefits of Mridaparikshak

Ease of operations and low running cost

Mridaparikshak is easy to operate, rapid, quantitative, and digital mini lab. It is a low cost laboratory (Costing Rs 86000/ + taxes). This laboratory can analyze 100 soil samples, each for fifteen parameters. Once the chemicals are exhausted, they can be refilled for Rs 17000. It can be easily transported to village and the soil analysis can be performed right at the farmers' doorstep. Because of these features, the mini laboratory could be a boon in the Central Governments' Soil Health Card (SCH) programme. According to SHC programme, more than 14 crore soil health cards are to be distributed to farmers at an interval of two-three years. This min laboratory can make this Programme realizable and achievable. It also reduces cost on power requirement since the equipment are customized to analyse only the required parameters and the equipment are also light weight. It ensures uninterrupted working since the power back up is provided (incorporated in shaker which can be connected to Smart Soil Pro) with the mini lab.

Economization in nutrient application, reducing fertilizer subsidy and increasing farmers' income

Mridaparikshak is expected to optimize and economize the application of major and micronutrients. It is expected to reduce the fertilizer nutrient applications considerably in the regions where the soil test levels (soil available nutrients) have become quite high as a result of heavy and indiscriminate use of fertilizers. Muralidharudu et al (2011) while analyzing the data of 430 districts found that the soils of about 57% districts were low in available N, 36% medium and 7% were high. Similarly, soils of about 51% districts were low, 40% were medium and 9% were high in available P. Available K status showed that the soils of about 9% districts were low, 42% were medium and 49% were high in available K status. There is considerable scope to reduce the fertilizer nutrient applications in the areas where soil test values have become high.

The balanced fertilizer application is especially important for India because a huge amount of foreign exchange is spent every year on import of fertilizers. Potassic fertilizers are entirely imported and almost 90% of the phosphatic fertilizers are also imported either as finished product or in the form of raw materials like rock phosphate, phosphoric acid, and sulphur (Subba Rao et al., 2015). Though urea is manufactured in India, still a large part of it is imported. Fertilizers, on account of high import cost, have to be subsidized. The total fertilizer subsidy in India in 2015-16 was around Rs. 73 thousand crore. Hence, soil fertility management and soil test based balanced fertilizer applications are most important aspects for

sustainable farming. Mridaparikshak can reduce the farmers' expense on fertilizers by optimizing the nutrient applications, thereby reducing the burden on imports and subsidy.

There is huge mining of micronutrients from soil without proper replenishment. As a result about half of the Indian Soils are suffering from Zn deficiency, 33% soils are deficient in B, Mn deficiency are coming up in rice-wheat growing areas of sandy loam soils in Northern India. The Fe deficiency has been a problem in upland soils. Hence, greater use of micronutrients with proper management strategies is essential for enhancing food production in future. Mridaparikshak prescribes balanced micronutrient recommendations such as Zn, Fe, Mn, B, and Cu.

Rapid and user friendly

Mridaparikshak reduces the time required in analysis of soil health parameters. The major advantage is that all the laboratory requirements are met at one place. The soil analysts need not run from one room to another for the analysis of soil samples, as in the traditional laboratory. Another advantage is the quick dissemination of soil test results. One of the main drawbacks in the traditional soil testing laboratories is the late delivery of soil test results. Mridaparikshak is provided with memory card on which the results can be stored and quickly transmitted to farmers' mobile. Mridaparikshak is easy to operate. It can be operated by young educated farmers/rural youths (11-12 Pass) with short training.

Minimal capital requirement

The biggest advantage is in the reduction of capital required for the establishment of laboratory. Traditional laboratories require huge equipment such as Atomic Absorption Spectrophotometer, Visible Spectrophotometer, Flame Photometer, Water Distillation Unit, Large Weighing Balances, Voluminous Shaker, air-conditioners etc. The total cost of these equipment is Rs. 3000000/. In addition, they require a large area (around 400 sq metre) to accommodate these equipment. The total cost of establishing a new laboratory comes out to be rupees one crore which is the biggest deterrent in expanding the network of soil testing laboratories in the country. In contrast, Mridaparikshak costs only Rs 86000/ for estimation of 100 soil samples, and subsequently Rs 17000/ as refilling cost to analyze another 100 soil samples.

Soil Health Card Scheme of Government of India for balanced fertilizer application and on-line fertilizer recommendation system

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Food Security and Indian Agriculture

Food Security is a global Challenge and it's a national challenge as well. It assumes special significance for India, being the second largest populated country. To maintain self sufficiency in food grains production agriculture growth on sustainable basis is utmost warranted. Indian Agriculture accounts for about 14 % of GDP with annual average growth rate of 3.6% in production. It provides livelihood to about 58% of the population and contributes 14% of total exports. Area and landholdings statistics show net sown area of 142 million hectare spread across multiple (15) agro-climatic zones and net irrigated area of 56 million hectares. 85% of landholdings are Marginal (less than 1 ha) and Small (1-2 ha).

Principal Crops and Production

Three major groups of crops include foodgrains (rice, wheat, pulses) with production of 245 million tonnes; oilseeds with production of 29 million tonnes and cash crops (cotton, sugarcane, jute) with production of 365 million tonnes.

National Agriculture Policy

For sustainable agricultural transformation there is an urgent need for policies with focus also on small holdings, rainfed areas, and backward regions with focus on achieving self sufficiency in food grains production. National policy seeks to overcome challenges and achieve annual growth rate of more than 4% on sustainable basis; efficient use of natural resources (soil, water, bio-diversity etc); availability of inputs (seeds, fertilisers, implements and credit facilities at affordable prices for farmers; socio-economic well-being of farmers, besides production and growth; equity across all classes of farmers/regions; and sustainable agriculture, the major policy focus for India.

Indian Agriculture – Thrust Areas

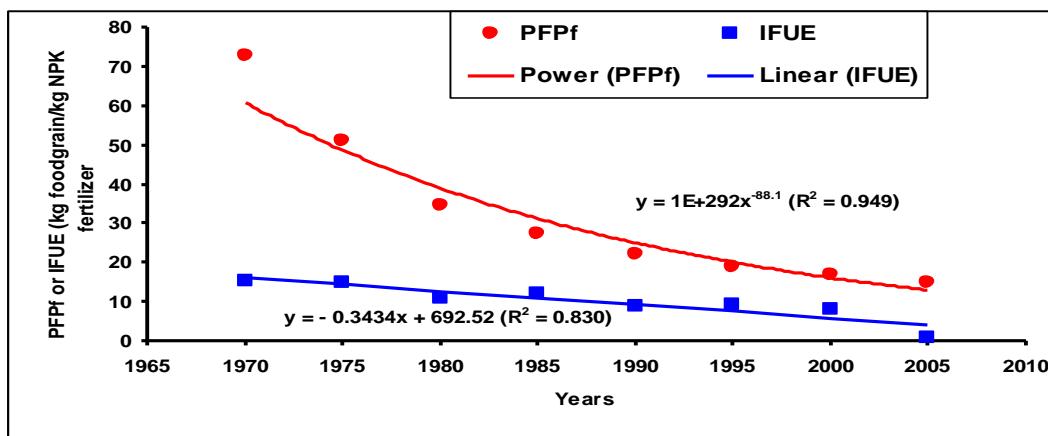
- Diversification of Agriculture
- Development of high yielding and climate resilient varieties of crops/seeds
- Water Management
- Conservation of soil and bio-diversity
- Soil Health Management
- Organic Farming
- Agri-Clinics and Agri-business Centres
- Farm mechanization

National Soil Health Policy (*Objectives of Government of India*)

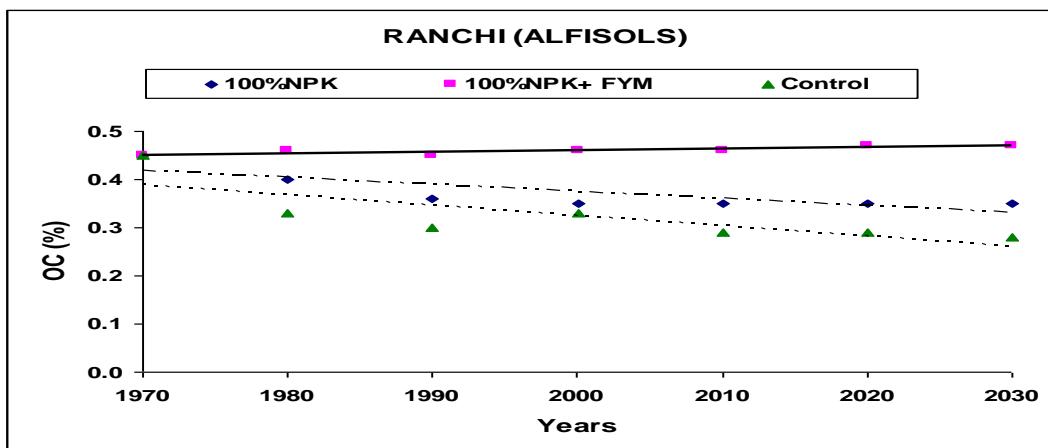
- Promote Integrated Nutrient Management (INM) through soil test based balanced use of nutrients, in conjunction with organic manures
- Strengthening soil testing facilities
- Soil test based recommendations to farmers
- Promote use of soil amendments for reclamation of acidic/ alkaline soils

- To support various types of soil and land resource surveys for creating a comprehensive soil database

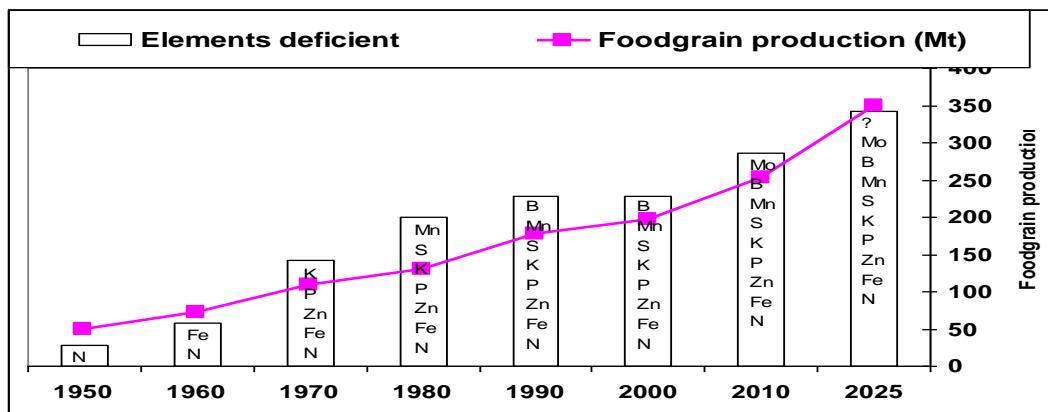
The need for the New Scheme
Declining partial factor productivity



Declining organic matter status where no manures are provided



Emerging nutrient deficiencies



The Remedy

STCR-IPNS approach of plant nutrition is the key

The fertilizer recommendations based on qualitative/semi-quantitative approaches or methods do not give expected yield responses. Therefore, inductive approach, a refined method of fertilizer recommendation for varying soil test values has been developed by All India Coordinated Research Project Soil Test Crop Response (AICRP-STCR) for different crops under different agroecological subregions. Soil Test Crop Response studies have used the targeted yield approach to develop relationship between crop yield on the one hand, and soil test estimates and fertilizer inputs, on the other. Considerable agronomic and economic benefits were accrued when farmers applied fertilizer nutrient doses based on soil test. Lately, the calibrations are being developed under integrated supply of organics and fertilizers keeping into account the nutrient contribution of organics, soil and fertilizers. The technology of fertilizing the crops based on initial soil test values for the whole cropping system is also being generated. Studies on soil biological parameters in guar-wheat cropping system under arid condition revealed that soil microbial biomass, dehydrogenase activity and organic carbon was higher in STCR based nutrient application as compared to general fertiliser recommendations. Ready reckoners in the form of fertilizer prescription equations have been developed by different centres for facilitating users for profitable use of fertilizers based on soil test values and the same has been demonstrated through various multi-location / verification follow up trials as well as front line demonstrations. In these trials soil test based rates of fertilizer application helped to obtain higher response ratios and benefit: cost ratios over a wide range of agro-ecological regions. It is evident that STCR based approach of nutrient application has definite advantage in terms of increasing nutrient response ratio over general recommended dose of nutrient application. Front Line Demonstrations conducted under Tribal Sub Plan (TSP) in Assam, Bihar, Chhattisgarh, Gujarat, Himachal Pradesh, Jammu & Kashmir, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Odisha, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh and West Bengal with tribal farmers' also clearly brought out the superiority of STCR-based fertilizer recommendation for different crops over blanket recommendation and farmer's practice.

Initiatives

- **Till 2014, the Government of India's initiatives**
 - Setting up and strengthening of soil testing laboratories
 - Trainings for staff / extension officers / farmers
 - Demonstrations on balanced use of fertilizers
 - Creation of district soil fertility maps
 - Issue of Soil Health Cards
 - Mainly State Governments initiatives
 - No uniformity
- **For sustainable agriculture - Need felt for policy with focus on**
 - Educating the farmers directly on soil health management
 - Issue of Soil Health Cards to farmers once every three years
 - Uniform approach
 - Covering all the groups of farmers
 - Covering both irrigated and rainfed areas

Objectives of Soil Testing – Soil Fertility Evaluation

- Assess nutrient status of soil-crop system
- Diagnose suspected nutrient imbalances
- Monitor effects of management on crop nutrient status and soil fertility
- Provide basis for making fertilizer recommendations for
 - improving crop yield and quality
 - improving fertilizer use efficiency
 - decreasing impacts on water quality
- Assess availability of toxic elements

- Improve soil quality

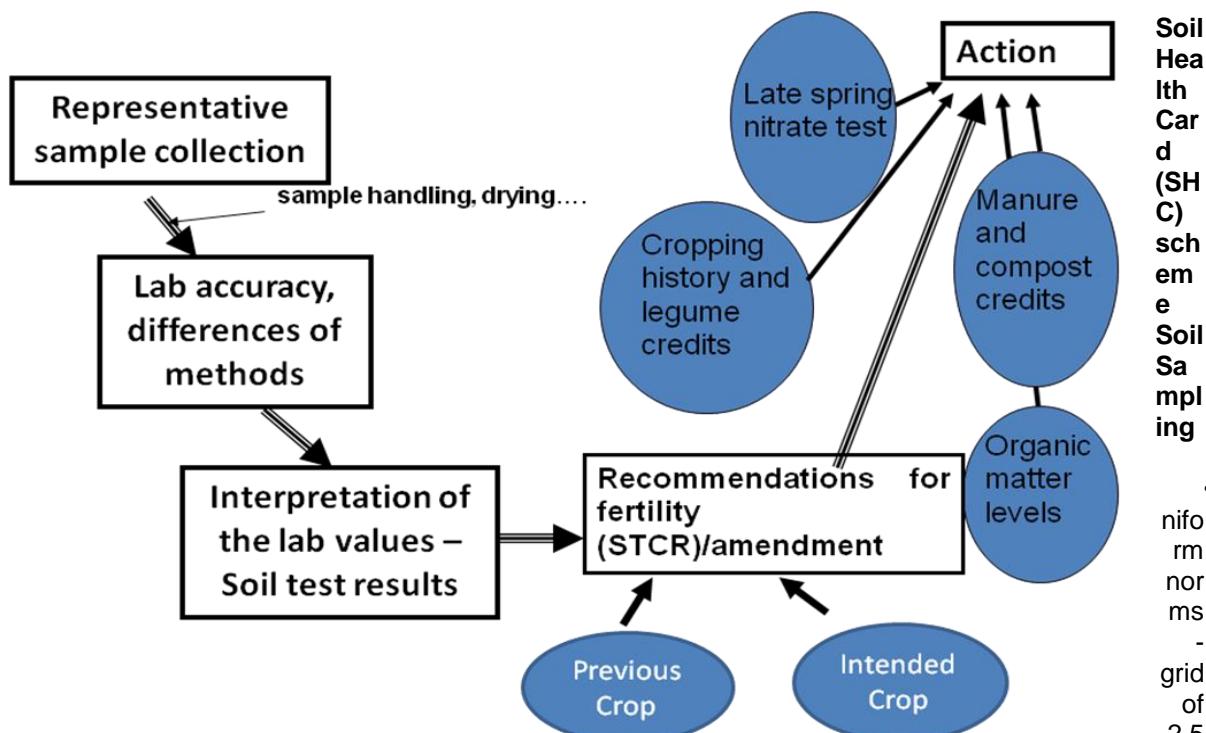
Comprehensive Soil Health Card scheme – launched in 2015

Unique Features

- Issue of SHCs to all farmers once in every three years
- Uniform approach to collection of soil samples and testing
- Fertilizer recommendation based on crops as against general recommendations
- Universal coverage of all the farm holdings



Soil Tests – the art and the science



ha in irrigated area and 10 ha in rainfed area (Srivastava et al., 2015)).

- GPS based soil sampling mandatory - to create a systematic database and allow monitoring of changes in soil health

Soil analysis

- Uniform soil testing methodology
- 12 parameters being analyzed for comprehensiveness
- Mandatory analysis of secondary and micronutrients
- Country-wide campaign for the training of soil testing staff

Issue of Soil Health Card

- Uniform format of Soil Health Card
- Soil test based crop-wise fertilizer recommendation in the soil health card
- Soil Health Card portal developed
 - For online generation of soil health cards and fertilizer recommendation.

Tasks/Requirement

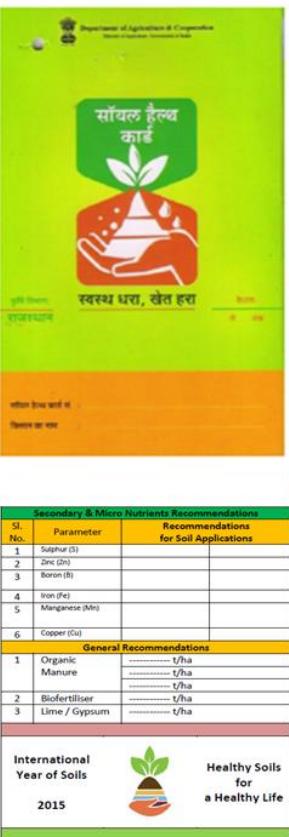
- Total of 2.53 crore samples – collected and tested in 3 years
- Issue of about 14 crore SHCs
- Facilities in Soil testing laboratories for testing all parameters
- Trained manpower for
 - Collection of samples
 - Testing
 - Database management
- Soil Sampling – Season influenced, limited window of maximum 5 months
- Soil testing – Season neutral, continue all 12 months

Micro Level Planning

Unit-wise mapping of target to resources (Total 676 units)

- Mapping brings out unit-wise
 - Number of samples to be collected/tested on monthly basis
 - Manpower available vis-à-vis required for collection/testing
 - Laboratories available vis-à-vis required for testing
 - Manpower required for database management
- Necessary steps initiated to bridge the gap between available and required resources

Soil Health Card Format

 <p>The SHC template is divided into several sections. The top section is a green header with the text 'सौर्योली हेल्पर्स कार्ड' (Suryolी helpers card) and 'स्वस्थ धरा, स्वेच्छा हरा' (Swasth Dara, Svechha Hara). Below this is a yellow section with 'ग्राम पंचायत' (Gram Panchayat) and 'पर्यावरण' (Environment). The main body is a green table with sections for 'Farmer's Details', 'Soil Test Results', 'Soil Sample Details', and 'Fertilizer Recommendations'. The bottom section is a red footer with 'International Year of Soils 2015' and 'Healthy Soils for a Healthy Life'.</p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th colspan="2" style="background-color: #2e8b57; color: white;">SOIL HEALTH CARD</th> <th rowspan="2" style="background-color: #2e8b57; color: white;">Name of Laboratory</th> <th colspan="4"></th> </tr> <tr> <th colspan="2" style="background-color: #2e8b57; color: white;">Farmer's Details</th> <th rowspan="2" style="background-color: #2e8b57; color: white;">S. 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SoilHealth Card Portal

Features

- A single, generic, uniform and web based software;
- Accessed at the URL www.soilhealth.dac.gov.in ;
- Uniform adoption of codes e.g. Census Codes for Locations;
- Sample tracking and alerts to farmers through SMS & email;
- Soil test based Fertilizer Recommendations generation;
- National database on Soil Health;
- Common format for Soil Health Card for all States;
- Acknowledgement receipt;
- Local language interface;
- Role based access.

Modules

- Sample Registration
- Soil Sample Test Result Entry
- Fertilizers Recommendations
- Generation of Soil Health Card
- MIS

Chemical Characteristics and Generalized Recommendations for Saline, Non-Saline Sodic and Saline Sodic soils

Soil	EC(dS/m)	pH	Recommendations
Saline	> 4.0	< 8.5	Leaching of salts, sub-surface drainage
Sodic (non-saline)	< 4.0	> 8.5	Gypsum application @ 5-10 t/ha
Saline Sodic	> 4.0	< 8.5	Gypsum application @ 5-10 t/ha followed by leaching of salts with fresh water

General Recommendations for amelioration of acid soils

For soils having pH < 5.5, application of lime @ 3-4 q/ha in furrow for each crop is recommended except for low land rice.

On-line fertilizer recommendation systems: DSS

<http://www.stcr.gov.in>

All India Coordinated Research Project on Soil Test Crop Response (AICRP-STCR) based at Indian Institute of Soil Science has developed a computer aided model that calculates the amount of nutrients required for specific yield targets of crops based on farmers' soil fertility (Majumdar et al. 2014). It is accessible on Internet (<http://www.stcr.gov.in>). This software program reads data, performs calculations and generates graphical and tabular outputs as well as test reports. This system has the ability to input actual soil test values of the farmers' fields to obtain optimum dose of nutrients. The application is a user friendly tool. It will aid the farmer in arriving at an appropriate dose of fertilizer nutrient for specific crop yield for given soil test values (Fig. 1). Efforts are on way in developing bioinformatics, E-choupals, digital libraries and e Governance that can benefit agriculture immensely by way of providing information and assisting the users in adopting the newer technologies.



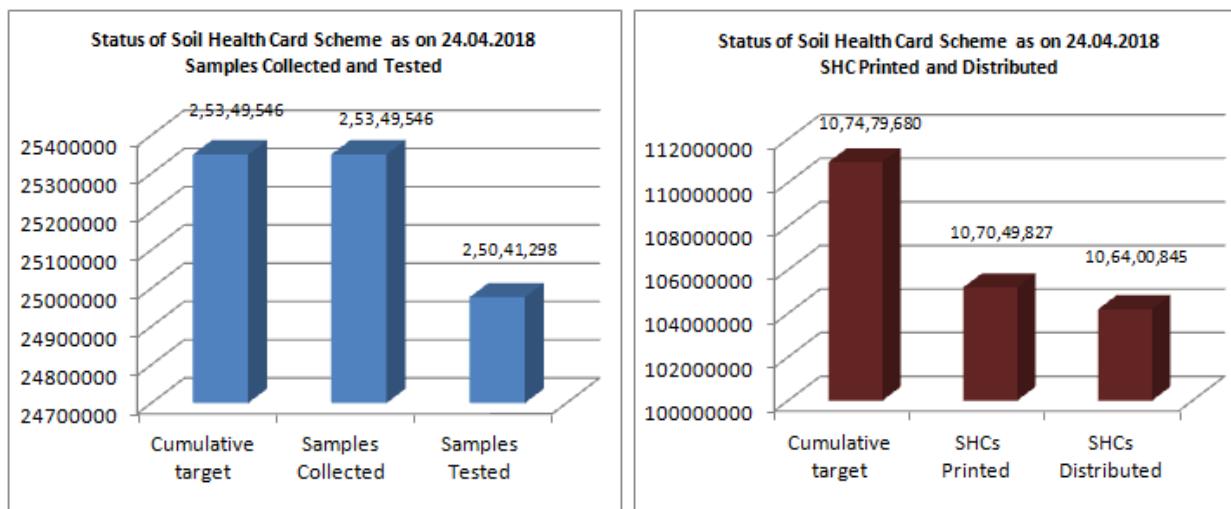
Fig.1. Internet enabled soil test based fertilizer application software

<http://www.soilhealth.dac.gov.in>

Recently the soil health card portal has been developed by Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Govt. of India for registration of soil samples, recording test results of soil samples and generation of Soil Health Card (SHC) along with Fertilizer Recommendations through STCR prescription equations which is a single, generic, uniform, web based software accessed at the URL www.soilhealth.dac.gov.in. It is a workflow based application with following major modules: (i) Soil Samples Registration, (ii) Test Result Entry by Soil Testing Labs, (iii) Fertilizer Recommendations, (iv) Soil Health Card generation along with Fertilizer Recommendation and amendment suggestions, and (v) MIS module for monitoring progress. It promotes uniform adoptions of codes, e.g., Census Codes for locations. The system has sample tracking feature and will provide alerts to farmers about sample registration and generation of Soil Health Card through SMS and Email. Based on test results, these recommendations will be calculated automatically by the system. The System envisages building up a single national database on soil health for future use in research and planning (Dey, 2016).

Progress under SHC Scheme

More than 101 millions SHC cards (the status, as on 16 January, 2018), so far has been printed and distributed among the farmers. The same is graphically represented below:



Impact of SHC Scheme

An impact study was conducted in 76 districts in 19 States covering 170 soil testing labs and 1700 farmers. It was observed that application of fertilizer and micronutrients based on Soil Health Card

recommendations resulted in 8-10 % of savings. Overall increase in the yield of crops to the tune of 5-6% reported by adopting the SHC recommendations.

References

Dey, P. (2016). Soil Health Management. In Soil Health: Concept, Status and Monitoring (Katyay, J.C., Chaudhari, S.K., Dwivedi, B.S., Biswas, D.R., Rattan, R.K. and Majumdar, K. Eds.). *Bulletin of the Indian Society of Soil Science*, 30, pp. 79-97.

Srivastava, Sanjay, Jha, Pramod, Tripathi, A.K., Dey, P. and Patra, Ashok K. (2015). Assessment of Soil Health and Preparation of Soil Health Card. ICAR-Indian Institute of Soil Science, Bhopal.

Conservation agriculture for sustainability of crop productivity and soil health

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Conservation Agriculture (CA) is an approach of managing agro- ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. Adoption of Conservation agricultural practices has helped millions of farmers worldwide in increasing productivity and profitability through arresting land degradation, improve input use efficiency, adapt and mitigate climatic extremes, and improve farm profitability in diverse ecologies across the world. The CA based crop management technologies being practiced over 155 m ha globally have helped millions of farmers through arresting land degradation, improve input use efficiency, adapt and mitigate climatic extremes, and improves farm profitability in diverse ecologies across the world. Realizing the potential impacts of CA, since mid 1990's, significant efforts have been made in the direction of adoption and popularization of conservation agriculture that resulted in adoption of these practices on more than 10.3 million ha area in Asia. Conservation agriculture and its fundamental principles: minimum (or no) soil disturbance, permanent soil organic cover and crop rotation /intercropping certainly figure among the possibilities that contribute for a sustainable soil management. CA is characterized by three linked principles, namely:

1. Continuous minimum mechanical soil disturbance.
2. Permanent organic soil cover.
3. Diversification of crop species grown in rotations, sequences or associations.

Keeping above in view efforts were initiated at ICAR –IISS Bhopal to Develop and validate location specific CA technologies for sustainable intensification of cropping systems across agro-ecologies with four sub-projects.

1. Demonstration of Best-Bet Conservation Agriculture Practices on Farmers' Fields in Vertisols of Central India.

Treatment	Plant height at harvest	Pods/plant	Grain yield q/ha	Straw yield q/ha
ZT	40.06	20.50	5.95	9.90
RT	39.66	19.66	5.23	9.58
CT	39.26	20.83	4.63	9.08
FP	38.33	18.33	4.06	8.99



2. Fine-tuning of Conservation Agricultural Practices for Vertisols of Central India

Treatment	From 2017 onwards
T1:	No Tillage (NT) with 30cm height residue
T2:	No Tillage (NT) with 60cm height residue
T3:	Reduced Tillage with 30cm height residue
T4:	Reduced Tillage with 60cm height residue
T5:	Conventional Tillage (CT)/Farmers practices
Nutrient Doses	
N1: 75% RDF	
N2: 100% RDF	
N3: STCR dose	

3. Development of Water and Nutrient Management Practices in Conservation Agriculture for Vertisols of Central India.

4. Impact of Conservation Agricultural Practices on Soil Health, Carbon Sequestration and Green House Gas Emissions in Different Production Systems.



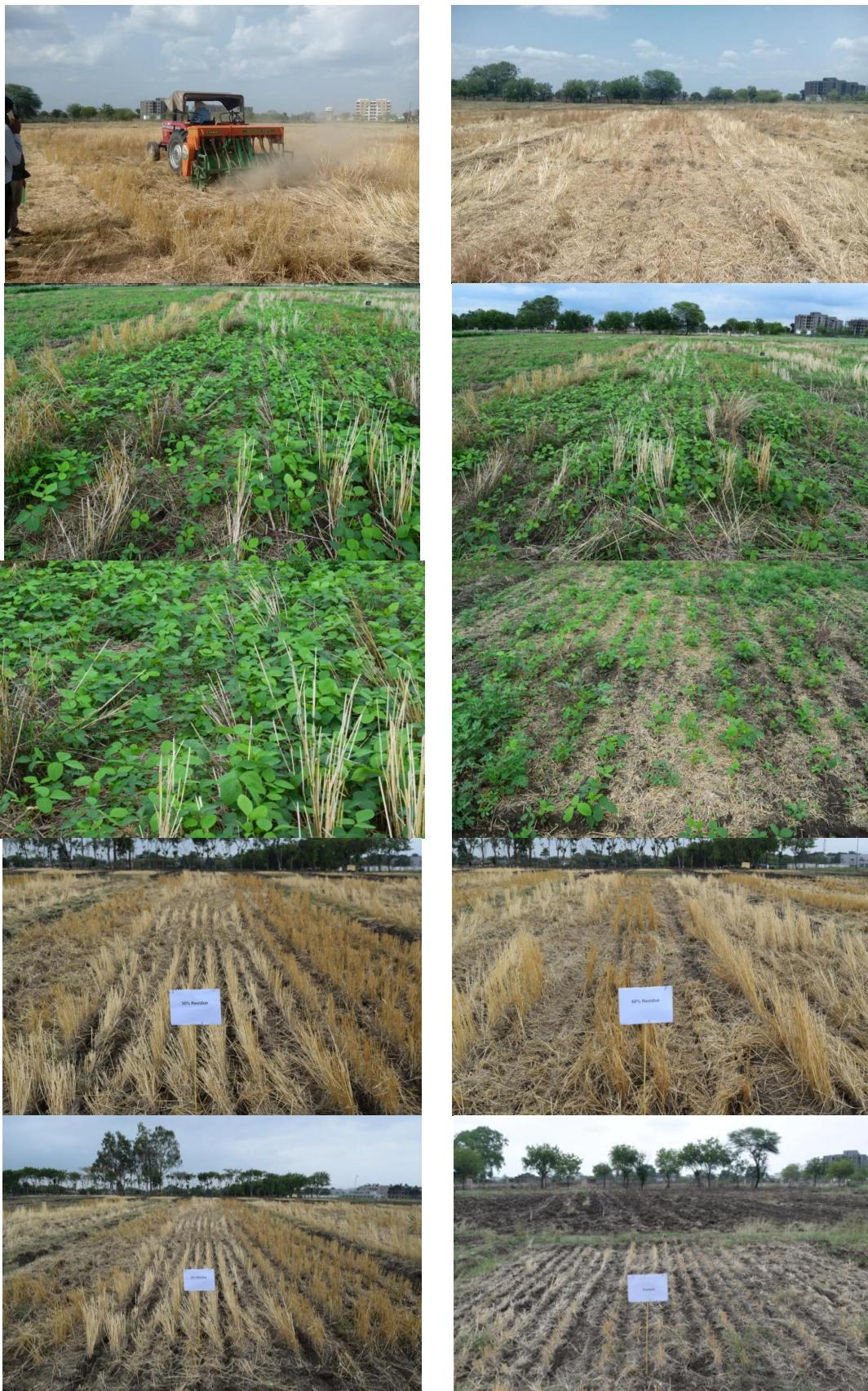


Fig 1. Crop establishment under Conservation Agriculture during 2017-18.

Effect of different residue levels on crop performance under conservation agriculture in vertisols.

The experiment was initiated with the aim to study the impact of different residue levels on crop establishment, ease of utilizing machinery (happyseeder) under different residue levels, weed management and resource conservation in terms of water and energy saving, in soybean –wheat and maize-chickpea cropping systems.

Soybean				
Treatment	Plant height at harvest (cm)	Pods/plant	Grain yield kg/ha	Straw yield kg/ha
T ₁ (Control)	44.50	20.66	658	1069
T ₂ (30% residue)	46.33	22.15	734	1133
T ₃ (60% residue)	47.67	24.00	758	1215
T ₄ (90% residue)	46.66	25.00	792	1259



Maize			
Treatment	Plant height at harvest	Grain yield q/ha	Straw yield q/ha
T ₁ (Control)	110.0	40.54	61.75
T ₂ (30% residue)	115.0	43.15	63.40
T ₃ (60% residue)	123.0	45.38	65.37
T ₄ (90% residue)	125.0	48.63	67.77

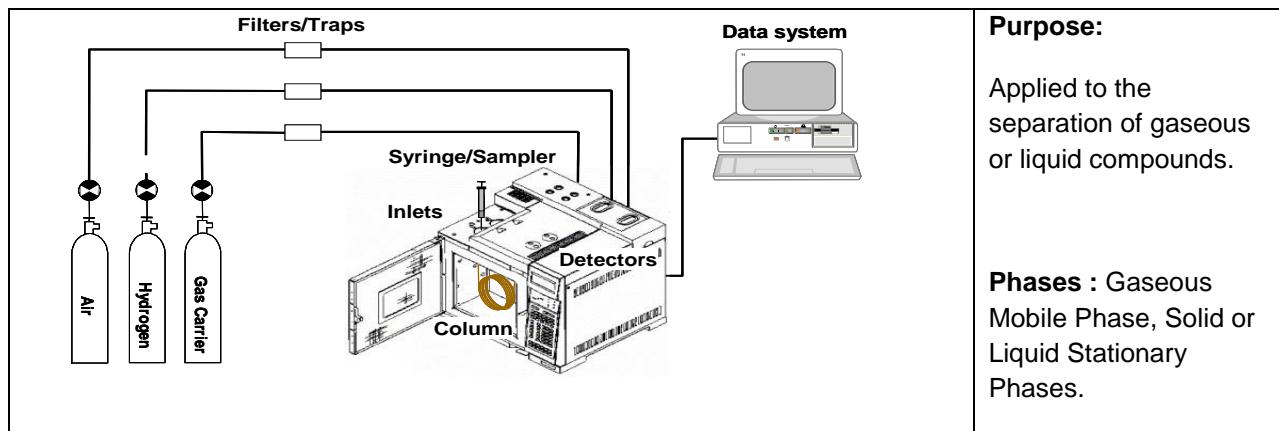


Sampling and estimation of Greenhouse gas by Gas chromatograph

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(Email: bharatik1@gmail.com)

Gas Chromatograph (GC)



GC components

Gas system – Carrier gas acts as mobile phase in the gas chromatography system (N₂, He, argon, etc). Other gases like H₂ and air are required depending on the detector type such as FID i.e flame ionization detector.

Injector – The Injection port where the sample is injected using a syringe or auto injector.

Column – Columns are two types, packed (old) or capillary (new). Packed type contains uniform silica particles (150-250 μ m) and surfaces are chemically modified. The columns themselves were either glass or stainless steel. The Capillary columns contain fused silica around the inner wall of column which like the particles in the packed column require chemical modification.

Oven – Two types, isothermal and gradient. The former type maintains single oven temperature while the later is capable of changing temperature which is very useful for separating various kinds of molecules.

Detector – There are different types of detector as follows.

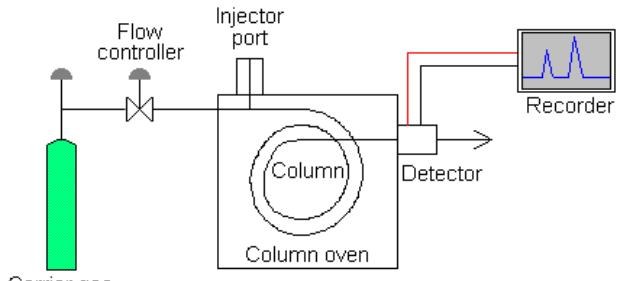
FID (Flame Ionization Detector) - High temperature of hydrogen flame (H₂ +O₂ + N₂) ionizes compounds eluted from column into flame. The ions collected on collector or electrode and were recorded on recorder due to electric current.

TCD (Thermal Conductivity Detector) - Measures the changes of thermal conductivity due to the sample. Sample can be recovered.

ECD (Electron Capture Detector) - ECD detects ions in the exiting from the gas chromatographic column by the anode electrode. The analytes are ionized by ionizing radiation i.e beta particles from the radioactive compounds.

Data system – Records and analyze signals.

Instrument

Schematic Diagram of Gas Chromatograph	Description
	<p>Mobile phase i.e carrier gas passes through column to detector.</p> <p>Sample is injected at injector, moves along with carrier gas through columns for separation. Column temperature can be regulated for optimum separation.</p> <p>Detector signals are recorded and computed through analog digital converter.</p>

Gas chromatograph Shimadzu 17A – Is a versatile GC equipped with FID and has packed column porapak N. This instrument is used to analyze CO_2 , CH_4 , and acetylene (for study of nitrogenase enzyme activity during biological nitrogen fixation by microbes). The carrier gas used is N_2 , while H_2 and air is used for FID operation.

Operation protocol of GC (Shimadzu 17A):

1. Power ON GC.
2. Run program (PeakNet) in the computer.
3. Open carrier gas and then air and H_2 tank.
4. Check pressure of three gasses, N_2 100 psi, H_2 100 psi and air 50 psi.
5. Press IGNITE button to start flame of FID. Check the flame of FID before any analysis.
6. Check for temperature profile. Column at 60C, injector and detector at 100C.
7. Open TIME PROGRAM, if any.
8. Inject air or blank sample (100 ul) at injector port using precision syringe (Hamilton).
9. Press START.
10. Data will be collected and check for baseline stability.
11. Once baseline is stable, inject sample.
12. Calculate peak area of the sample from standard peak area values.

Calculation :

Analtes	Retention Time (min)	Standard conc (ppm)	Standard Peak Area	Peak Area of unknown sample	Conc. of sample (ppm)
CO_2					
CH_4					

Mid-Infrared Spectroscopy for quantitative analysis of soil

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Monitoring of the factors controlling the soil health is important for improving and sustaining agricultural productivity and maintaining soil health. However, one of the main limitations in monitoring soil health is soil heterogeneity or spatial variability of soil properties. Although it is technically possible to perform a wide range of laboratory analyses of soil properties and derive a soil fertility or health index, but most of the required analysis are time consuming, labour intensive and costly which in practice, makes it un-economic to map the soil properties of a field with the required spatial and/or temporal resolution. Diffuse reflectance spectroscopy in the middle infrared region provides a good alternative that may be used to enhance and support conventional methods of soil analysis, as it overcomes some of their limitations particularly where high spatial density is needed. MIR spectra however need calibration and validation with the laboratory analyzed data for development of prediction models for different soil properties which will be valid for a soil type.

To develop a prediction model for vertisols, geo-referenced soil samples are collected from different land use systems to incorporate wide range of soil variability like, arable land under different cropping systems, fallow field, grassland, forest lands, and grazed lands and are analyzed for their physical and chemical properties in the laboratory. The mid-infrared spectra between 400 to 4000 cm⁻¹ wave number recorded using the FT-MIR spectrometer in the diffused reflectance mode of the soil samples after their mathematical pre-processing are used for development of mathematical models for prediction of soil properties. Different spectra pre-treatment techniques like, multiple scatter correction, standard normal variate, standard normal variate- detrending, first and second order derivative, are tested for processing the raw MIR spectra. It is observed that the first order derivative manipulation of the spectral data greatly enhances some of the spectral features and the second derivative enhances them even more. Different prediction models of soil properties are then developed using partial least square (PLS) regression and random forest regression technique with the pre-processed MIR spectra and laboratory generated soil properties data and then they are cross validated. The results from many preliminary studies indicate that the MIR spectroscopy can potentially be used for prediction of soil properties in Vertisols. However the models need to be revalidated with more independent soil data from a larger soil sample.

To start with, the geo-referenced soil samples are collected processed and mid infra-red spectra between 400-4000 cm⁻¹ wave number of the ground soil samples are recorded. Soil organic carbon (SOC), available N, P and K, EC, pH, sand, silt and clay content of the soil samples are determined following standard laboratory procedures. Some of the outlier wet chemistry data are identified and discarded following Dixon test. The Kennard-Stone (KS) algorithm method is then used for selection of representative data subsets for calibration and validation of models from the generated soil MIR spectra. About 70% data can be used for development of chemo metric model and 30% of soil sub-samples can be used for the model validation. Before further analysis, the MIR soil spectra are transformed to first derivative using Savitzky-Golay method. Then random forest regression method is used to develop prediction model for the various soil properties. Validation of the models is done with independent data set and the predictability is tested through coefficient of determination (R^2) values. Our experience at ICAR-IISS is that soil properties like pH, clay content, soil organic carbon, pH, total potassium content etc. for Vertisols can be predicted with reasonable accuracy using the chemometric models developed. However, predictability of available phosphorus, available nitrogen, and moisture retention at field capacity was quite low as evident from low coefficient of determination values and high RMSE values for these properties.

Open Top Chamber Facility for Climate Research

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Open Top Chamber Facility

The atmospheric CO₂ is one of the key variables affecting climate of the planet earth. The atmospheric CO₂ concentration has increased from 270 $\mu\text{mol mol}^{-1}$ in the pre - Industrial era to about 410 $\mu\text{mol mol}^{-1}$ in the year 2017. The Open Top Chamber (OTC) facility is used to study the climate effects on crops and plant species. The response of crops to elevated CO₂ and elevated temperature can be studied in OTCs. The OTCs are kept open from the top and thus simulate natural conditions. They are constructed using polycarbonate sheets covered from four sides with suitable dimension. The chamber material should be such that minimum 80-85% of the incident light passes through the chambers. At the research farm of the ICAR-Indian Institute of Soil Science, such facility has been developed with a funding from the National Agricultural Science Fund of the Indian Council of Agricultural Research. In the research farm, eight such chambers have been fabricated with control and automation facility.

CO₂ elevation

For studying the effect of elevated CO₂, arrangements are made for supply of CO₂ gas of required purity to the OTCs through connected nozzles. Carbon dioxide elevation at desired level can be achieved through continuous supply of CO₂ gas from connected CO₂ gas cylinders placed outside in a different room. The desired concentration of CO₂ in OTCs is maintained by an automated system involving series of sensors, solenoid valves, pressure regulators and discharge nozzles.



Open Top Chamber Facility for Climate Change Study at IISS, Bhopal



CO₂ gas cylinders



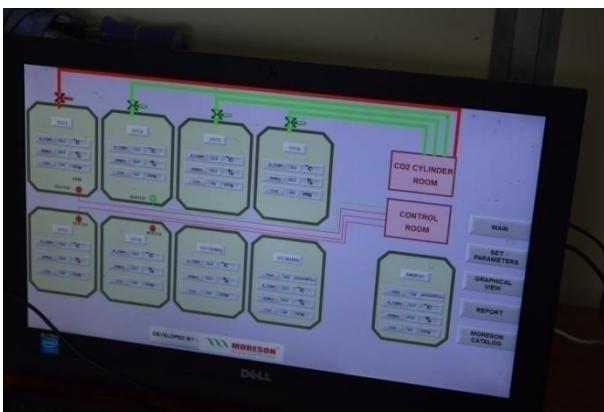
Pre-heaters



Pressure regulators and solenoid valves



Infra-red Heater and series of sensors



Data recording and monitoring



View of soybean crop in OTC

Control and automation system of Open Top Chambers

Sensors

The OTC Facility is provided with series of different sensors for measurement of data of various parameters. The sensors installed in OTC Facility are CO₂ monitors, air temperature sensor, soil temperature sensor, humidity sensor, soil moisture sensor, PAR sensor etc.

Data recording, monitoring and control

The data generated through different sensors are recorded and continuously displayed on the computer screen through the modulators using Supervisory Control and Data Acquisition (SCADA) system. The recorded data is used for automation and control of desired level of CO₂ and Temperature in OTCs. The sensor generated data is stored in computer storage for different research applications.



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