ISSS Bulletin No. 30

Soil Health:
Concept, Status and Monitoring

Indian Society of Soil Science
New Delhi
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Concept, Status and Monitoring

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Indian Society of Soil Science
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Soil Health: Concept, Status and Monitoring

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Preface

With the intent of raising level of awareness, appreciation and understanding on the role soils play in sustaining food security and securing essential ecosystem functions, Indian Society of Soil Science (ISSS) organized a special symposium during its 80th Annual Convention at the Campus of the GKVK UAS Bengaluru. The theme of this 06 December 2015 meeting nucleated around soil health management. Holding of this conference was one of the several events organized by the ISSS in commemoration of the UN 2015 International Year of Soils. This scientific discourse also concurred with the 2015 launch of the GOI Soil Health Card Mission at a cost of Rs 5.6854 billion.

Executive Council of the ISSS in its meeting, held on 21 March 2015, decided on the organization of the symposium, 'Soil Health: Concept, Status and Monitoring' during the 80th Convention. It also approved to produce the presentations in the form of a Bulletin. The entire task of selecting topics, identifying the invited speakers to make presentations and turning these in the form of a Bulletin was assigned to a Committee guided by JC Katyal with SK Chaudhari, SK Singh Members and Dr DR Biswas as Member Secretary. Keeping in view the tight schedule on bringing out a well-rounded publication, Drs RK Rattan, BS Dwivedi and K Majumdar were co-opted to give their input in successful organization, editing and other logistic support.

The symposium comprised of 5 formal presentations by the leading Soil Scientists of India. The current bulletin begins with a paper on, 'Global Review on State of Soil Health'. Authored by J.C. Katyal, S.P. Datta and D. Golui, it outlines concept of soil health, how it is assessed, benchmarked and managed. It also traces the causes of fall in health of world soils, resultant economic and environmental consequences due to that. It goes on to suggest a way forward to halt the further harm and restore that what has already been inflicted. This chapter is followed by a paper entitled 'Soil Health in India: Retrospective and Perspective' by SK Chaudhari. It describes health of Indian soils and links their current unacceptable state with misuse and imbalanced application of native sources and man-made inputs. It lays emphasis on an integrating revival plans that uplift not only soil chemical and physical attributes but makes a strong case for elevating depth and intensity of useful soil biology. The next article, scripted by Biswapati Mandal, Nirmalendu Basak, Satadeep Singha Roy and Sunanda Biswas, describes 'Soil Health Measurement Techniques'. The paper holds anthropogenic interventions leading to deplorable state of current health of soil resources. As the title tells, this manuscript details methods of measuring critical properties that describe soil health. Linking with soil health sustaining goals, Mandal and his colleagues have made a valuable attempt in arriving at the indicators that capture the nuances linked to soil health processes and functions. For the purpose of making an effective and comprehensive assessment of soils, it is stressed that soil health indicators, besides aligning with eco-system functions, must be sensitive to variations in management practices and be inexpensive, reproducible and easy to calculate and interpret. 'Soil Health Mission: Government Initiatives' by Ashok Dalwai and Vandana Dwivedi is the theme of the 4th chapter. According to authors, Department of Agriculture and Cooperation and Farmers' Welfare of the Ministry of Agriculture, Cooperation and Farmers' Welfare accords top priority to maintenance of health of the Indian Soils. Recently launched Soil Health Cards Scheme under the auspices of the National Mission on Sustainable Agriculture is a testimony to the GOI resolve on minimizing further deterioration in soil quality. Soil Health Card Scheme, covering all the 140 million India's farm holders is seen to facilitate building a comprehensive soil database and help monitoring the changes occurring in the soil health status periodically. It is a scheme that genuinely welds together research, extension and development initiatives. The final and 5th article of the bulletin 'Soil Health Management' by P. Dey narrates that infusion of holistic soil management is sine qua non of sustainable development of agriculture. On the one hand, the author calls for elevating soil quality by use of chemical fertilizers on the basis of soil test values, yield targets and biophysical conditions, on the other, he stresses to harmonize the modern techniques with the indigenous knowledge and knowhow by partnering with client farmers. A focused emphasis, with evidence, on the vitality of the integrated soil nutrient management and supply in conserving soil health is the high point of Dr Dey's presentation.

The editorial team places on record its indebtedness to authors of various chapters for the excellent cooperation extended by them in timely completion of the publication. It also shows it gratefulness to the Executive Council led by Jagdish Prasad, President of the ISSS for the logistic and professional support. The acknowledgements will be incomplete without recognizing the untiring services rendered by the Secretariat of the ISSS. Its support and assistance is thankfully appreciated.

It is the fond hope of the ISSS and the Editorial Committee that the Bulletin, 'Soil Health: Concept, Status and Monitoring' shall act as a useful reference document for use by the professionals, technocrats, development functionaries and students concerned with the sustainable management of soil health. Its publication is seen timely in giving specific impetus to the Government of India's initiative on Soil Health Cards Scheme.

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Global Review on State of Soil Health

J.C. Katyal, S.P. Datta and D. Golui

"Agriculture must, literally, return to its roots by rediscovering the importance of healthy soil, drawing on natural sources of plant nutrition, and using mineral fertilizer wisely" (FAO; http://www.fao.org/ag/save-and-grow/index_en.html).

Soil and Soil Health: Definition and Concept

Soil: Soil is a marvelous gift of nature to mankind. Without the presence of this thin layer on the top of lithosphere, there would have been no life on the planet Earth. Hinduism pronounces 'Man's journey in the world begins with soil and ends with soil'. Kellogg (1938) expressed that soils and humans have evolved together. A priory, 'health of the soils a nation owns determines the quality of well-being of its people'. Humans for their own survival and for the sake of survival of their future generations, therefore, must not violate the quality of the soils inherited by them (Chief Seattle 1855). It is widely proclaimed that rise and fall of ancient civilizations were led by the sustenance or deterioration in quality of soils. It, hence, becomes incumbent on mankind to treat soil as part of their 'community' and not as a 'commodity' to be used and thrown away (Prithvi Sukta, AV circa 1000 BC; Leopold 1949).

Soil has been described in several ways; from solid ground (solum) to dirt and to the nurturer of the universe. Capturing the essence of definitions given by soil scientists, it is portrayed as:

- a natural body derived from weathering of rocks,
- three dimensional, having length, breadth and depth,
- anisotropic, because of differing values in its characteristics across directions,
- multiphasic-mineral solids, organic matter, water and air are its constituents. Solids are made up of pulverized rocks, represented by gravel, sand, silt and clay. Organic matter is formed of living organisms and dead plant and animal residues. Water is present as solution of plant available nutrients (ions) and soluble organic radicals. Soil air is typically enriched with carbon di-oxide (CO_2) and
- anchor of plant growth. Different soils exhibit different productivity potential, which is influenced by man's use of soil.

Each element describing soil is assigned a special function to perform – either independently or jointly with others. Soil depth helps in water stocking, filtration of contaminants and provides volume for roots to respire and feed the above ground growth with vital nutrients and water. Soil mineral matter and breakdown products of organic matter associate in performance of these tasks. Composition and texture of solid mineral matter – a product of the kind of parent material and soil forming processes is the primary source of essential plant nutrients and water holding/ transmission properties of a soil. These are also the key determinants of inherent soil quality. Soil organic matter's dead fraction is decomposed by living soil organisms into forms that are used by microbes for their growth and multiplication. In return, exudates generated by the microbes and plant roots help building soil aggregates contribute to soil aeration and conduct of water in the soil. Decomposition also mobilizes essential nutrients and helps building soil fertility. Other decay products of organic matter are humus and CO_2. While humus is helpful in stabilizing aggregates, storing nutrients and water and immobilizing polluting chemicals, CO_2 is a greenhouse gas. It is a major contributor to ongoing global warming.

Soil is an ecology or part of ecology. It shelters more biodiversity in number and kind than all other biota together (Blum 2002). The diverse soil organisms interact with each other, and with the environment around them. If that living environment changes, soil organisms get affected and a disturbing cycle of events sets in motion. The result is soil's functions like aggregation, aeration, hydro-holding and transmission properties, nutrient mineralization, ability to bind polluting chemicals, climate regulatory function and potential productivity get negatively affected. Man has a dominating role in influencing the native web of soil life by changing its living environment.

Soil health: A soil that is able to optimally sustain its native/acquired productivity potential and render ecological services is said to be in good health. The term 'soil health' invariably crosses roads with other name 'soil quality'. The pioneer textbook on Soil Science, 'Nature and Properties of Soils' 14^{th} Edition (Brady and Weil 2013) describes the concepts of soil health and soil quality. According to the text "Although these terms are often used synonymously, they involve two distinct concepts. The soil health refers to self-regulation, stability, resilience, and lack of stress symptoms in a soil as an ecosystem. Soil health describes the biological integrity of the soil community - the balance among organisms within a soil and between soil organisms and their environment". Soil health concept involves integration of physical, chemical and biological properties of a soil and role of this harmonious blend in sustaining productivity growth and environmental security. Cited from FAO (www.fao.org/agriculture/crops/thematic.../soil...of-soil/ ...healthy-soil/en/), soil health is the capacity of a soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. The Soil Science Society of America defines soil health 'as 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'. Several others (Doran and Parkin 1994; Karlen *et al.*1997) have proposed near similar concept of soil health. Across various concepts/definitions, soil biota is given prominence in a soil's functioning. This feature distinguishes term soil health from soil quality (Brady and Weil 2013). Soil quality, therefore, in contrast is the term that more often is used to illustrate physical and chemical attributes of a soil and their place in plant growth and environmental regulatory functions. These characteristics range between a simple trait like soil colour to more complex properties like fertility, erodibility and compactability.

Despite some visible dividing lines, largely soil health and soil quality are used interchangeably. According to Harris and Bezdicek (1994), scientists, in general, prefer to employ the term 'soil quality', while producers and commoners choose 'soil health'. Generally, in the current context the term soil health is preferred, for it portrays soil as a living and dynamic organism that functions holistically rather than as an inanimate mixture of sand, silt, and clay. Knowing that soil is a living body, some equate soil health to the health of *Homo sapiens*. In fact, multi-phasic and 3-dimensional soil framework provides the ground for comparing it with the human anatomy. Pitching functions of soil versus operative system of a man's body, for instance, exhibit: decomposition of organic matter in a soil relates with digestive system, clay with human brain, air circulation and exchange parallels respiratory system and leaching of salts resembles excretory system and so on. Also, appended word health to soil connotes either a soil being robust or an ailing entity. A soil in poor health, like the human body, mal-functions, needs more inputs, uses them inefficiently, gives less productivity per unit of input and its productivity potential gets weakened with time. As far as the phrase 'soil quality' is concerned, this report does not distinguish it from the expression 'soil health'. Accordingly, one term substitutes the other to retain flow of the write up and readability. A graphical representation of soil quality concept is presented in figure 1. Besides, the functions depicted in this figure, as pronounced earlier, soil also performs a gratifying task of food and raiment production for mankind.

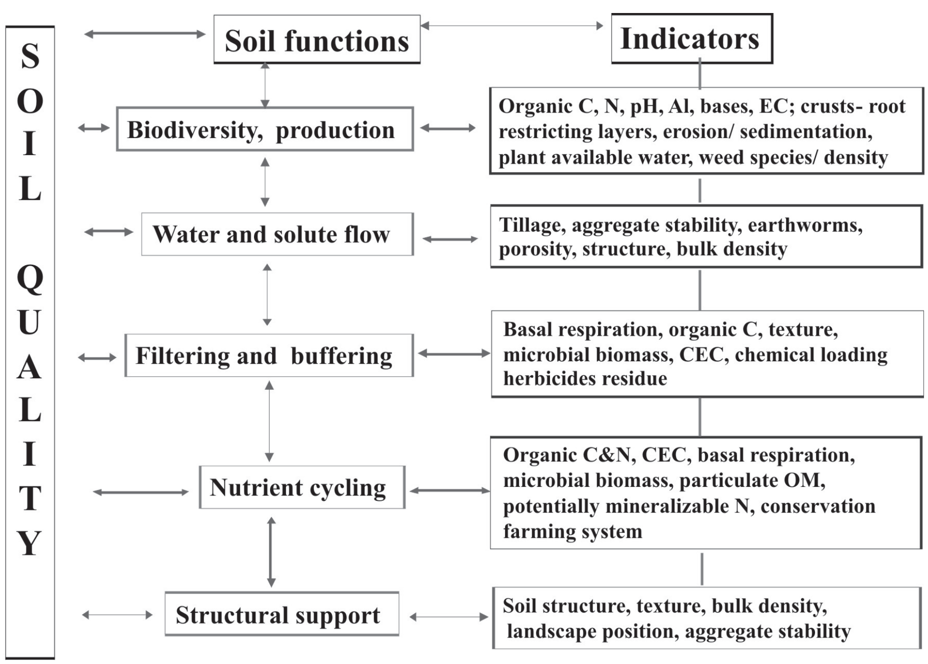


Figure 1. Graphical representation of the concept of soil quality
Source: Seybold *et al.* (1997)

Maintaining soil in optimum health is a prerequisite to support necessary food grain production and sustain ecological services. This gains further importance, since global surface area – 51 billion hectares (Bha), is unfavorably divided between land and oceans. According to Earth's Fast Facts (http://www.planetpals.com/planet2.html), total land mass occupies 30% (14.8 Bha); oceans cover rest of the universe. Of the total land mass, merely 11% (~1.6 Bha) of the earth's soil area is used to grow food (FAOSTAT 2014). Remarkably, with limited areal extent, arable soils produce 98% of the world's food; oceans contribute just 2% (http://core.ecu.edu/geology/woods/SEARESOURCES.htm). Vitally, therefore, a soil's productivity must be sustained, since on its quality hinges the production of enough food and biomass for sustenance of heterotrophs. Then soil supporting perennial vegetative shield in the form of forests is a giant economic and ecological reservoir. By generating a vast variety of public goods, forests are an immense source of life and living. Additionally, value of forests in sustaining biodiversity, building aquifers, preserving soil integrity and maintaining healthy climate is indescribable.

Soil Health Assessment: Productivity is a function of crop genotype, ambient environment and its management. Soil is the most significant milieu that roots confront to feed the above ground growth and yield of crops. A number of soil properties narrating their optimum state and level for plant growth and relating sustenance of ecological services are assessed largely under controlled conditions. These attributes, divided into chemical, physical and biological properties, are measured and their parametric values are employed individually or jointly to assess the state of soil health. Following lab/field measurements help analysing and describing state of soil health (Table 1; refer to Figure 1 also):

Table 1. Measures of soil health

Chemical characteristics	Physical properties	Biological attributes
Soil pH, EC, SAR, fertility, contaminants and pollutants	Soil texture; soil depth; bulk density; available water holding capacity; surface and sub-surface compaction; soil structure (aggregate stability)	SOC; microbial biomass; microbial N; soil respiration; mineralizable N and S; soil pathogens

Based on findings of a large number of investigations, each soil characteristic is assigned an optimum value corresponding to good soil health. This number is called 'critical value' at which a pre-rated potential productivity, whether native or acquired, is not disturbed. When the measurement of a parametric attribute is lower or higher than the critical value and it causes productivity decline of more than 10%, it signals loss of soil health. It also means productivity will restore in response to application of that ameliorant. If it does not then it points to incidence of multiple constraints, which requires capturing the integrative role of various soil deficiencies vis-a-vis their joint regressive effect on yield. This explains need for development of soil health indices, an aspect narrated in a subsequent section.

Barring weathering induced features *e.g.*, soil texture and soil depth, man's management profoundly influences all the other soil health measures listed in table 1. Adoption of efficient handling of native resources and man-made inputs and induction of holistic land management technologies hold the key to sustain soil health and maintain lasting food security. Overexploitation, mismatches of land use and land attributes, empathy towards application of restorative management including efficient and balanced use of inputs and induction of land use policies discouraging adoption of relatively permanent land saving and conserving technologies inspire degeneration of native land quality. Fall in soil health opposes sustainable development (SD) of agriculture. As per TAC-CGIAR (Technical Advisory Committee-Consultative Group on International Agricultural Research), SD of agriculture espouses holistic management of soils (and other natural resources) to satisfy the changing human needs, while maintaining or enhancing their (and other natural resources) condition and that of the environment. In essence, sustainable agriculture manifests a fit between needs of humanity and health of soils and other natural resources. It is the holistic management of soils that props sustainable development by fulfilling necessary productivity and production growth to remain food secure and ecologically sound. In return, it establishes an everlasting commitment of human society on protecting, conserving and enhancing soil health.

Soil Health – Indexing: Soil health integrates all components of the soil system and is assessed by indicators that describe and quantify biological, chemical and physical properties. Soil characteristics (Table 1) that contribute to a healthy soil include: i) protected soil surface and low erosion rates, ii) a reasonable level of soil organic matter (>1%), iii) high biological activity and biological diversity, iv) good available moisture storage capacity, v) favourable soil pH, vi) deep root zone, vii) sufficient amount and balanced proportion of available nutrients, viii) resilient and stable soil structure, ix) adequate internal drainage, x) favourable soil strength and aeration, xi) favourable soil temperature, xii) low levels of soil borne pathogens, xiii) low levels of toxic substances and ix) ... (ellipsis means possibility of some more features). This list covers almost all important properties which decide and describe the state of soil health.

The properties that constitute a healthy soil are not common across locations and situations. Also farmers' laid out criteria for a healthy soil is not fixed. Primarily, it varies with their perception on the soil traits constraining expected yield. For some, the limitation may be infiltration rate, for others depth and still others it may be salts. Exactly for them and rightly so what constitutes a healthy soil depends on what constrains maximum the realization of normally realized productivity and profitability. It, therefore, seems justifiable to believe that there is no uniform or universal group of tests determining soil health. Several soil properties, whether they relate to chemical, physical or biological attributes, contribute to state of soil health and accordingly need assessment. In order to measure health of a soil, chemical and physical properties have long been studied by soil scientists and the basic tests and procedures are well established. Compared to that biological soil tests are fairly new to Soil Scientists. Not only is the novelty but there is also lack of unanimity among them on common biological assays determining soil health (Brevik 2009).

Despite diverse attributes and disagreement on common soil biological properties, attempts have been made to describe soil health by developing quantitative and qualitative indicators. An index is categorized non-quantitative, if it does not combine evaluated parameters into a numerical index that rates soils along a continuous scale. On the other hand, quantitative systems result in a numerical index, typically with the highest number being assigned to the best quality soils (Singer and Ewing 2000).

USDA Land Capability Class (LCC), a non-quantitative index, combines three rating values at different levels of abstraction: capability class, subclass and unit. At the most general level, soils are placed in eight classes, according to whether they: (a) are capable of producing normal growth and yield of adapted plants under good management (LCC I-IV), (b) are capable of producing specialized crops under highly intensive management described as "elaborate practices for soil and water conservation" (LCC V-VII) or (c) do not return on site benefits as a result of management inputs for crops, grasses or trees without major reclamation (LCC VIII). Within the broad classes are subclasses which signify special limitations such as erosion (e), excess wetness (w), problems in the rooting zone(s), and climatic limitations(c). Although an important constraint relates to possible land use and expected productivity and decides land capability subclasses, but it does not necessarily indicate the degree of the problem, say erosion, on a progressive and consistent basis. Several studies have shown that lands of higher LCC (LCC I, LCC II,…) exhibit greater productive capacity than lands of lower LCC (LCC V, LCC VI…) (Singer and Ewing 2000).

An attempt has also been made to develop quantitative soil health indices. A brief narration on initially proposed quantitative soil health indices (SHI) is presented in table 2.

Following the above listed initial attempts, Andrews *et al.* (2002) modeled soil quality indices by following additive, weighted additive and decision support criteria for vegetable production systems in Northern California. In fulfillment of this objective, they captured and integrated desperate values of macro-aggregate stability, available water content, bulk density, electrical conductivity, microbial biomass carbon, pH, potentially mineralizable N, respiratory quotient, extractable phosphorus, sodium adsorption ratio and soil organic carbon (SOC). Irrespective of the soil quality indexing method, management systems supporting OC build-up scored higher index value than the low input or conventional treatments. On this basis, it was concluded that a small number of carefully chosen soil quality indicators, when used in a simple, non-linearly scored index, can adequately provide information needed for selection of the best management practices. Likewise, Sinha (2007) evaluated different soil quality indices for tillage, water and nutrient management practices and concluded that a simple linear weight additive index is the best approach for quantifying the effects of these management practices on soil quality. Earlier, Glover *et al.* (2000) computed SQI for evaluating the effects of conventional, integrated and organic apple production systems on soil quality. They reported that the integrated production systems had a SQI of 0.92 (out of 1.0), which was significantly higher than the index rating of 0.78 for the conventional production system. Integrated farming scheme even over-scored in soil quality index than the organic production system (SQI 0.88). Additionally, their findings indicated that a well-developed SQI can provide an effective framework for evaluating the overall effects of different orchard production practices on soil quality. Other studies confirmed that mulching (Karlen *et al.* 1994) and

Table 2. A brief on early soil health indices

Soil health index	Measurements
Productivity index (PI) (Pierce *et al.*1983)	Developed to evaluate soil productivity especially with reference to potential productivity loss due to erosion. PI model rates soils (top 100 cm) on the grounds of volume sufficiency for root growth. It is calculated as potential to stock water, bulk density, aeration, pH and EC. A value from 0 to 1 is assigned to each property describing the importance of that parameter for root development. The product of these five index values is used to describe the fractional sufficiency of any soil layer for root development.
Soil quality index (SQI) (Parr *et al.*1992)	SQI is a function of soil properties, potential productivity, environmental factors, human and animal health, erodibility, biological diversity, food quality and safety and management input. Apparently, the determination of the specific measurable indicators relating to each variable and their interactions is a daunting task. Then the reference value that indicates a high quality soil is not specified.
Soil quality index (SQI) (Larson and Pierce 1991)	Quality is defined as the state of existence of soil relative to standard or in terms of a degree of excellence. The authors argue that defining soil quality in terms of productivity is too limiting and does not serve well. According to them changes in soil quality are functions of changes in soil characteristics over time.
SQI (Karlen *et al.* 1994)	SQI is based on a 10-year crop residue management study. Their index is based on four soil functions, *viz*. accommodating water entry, retaining and supplying water to plants, resisting degradation and supporting plant growth. Priories are then assigned weighting to each factor. The resulting index numbers vary from 0 to 1.

tillage practices (Hussain *et al.* 1999) exerted significant influence on quantitative values of indices describing soil quality. Results from India (Masto 2004; Gajri *et al.* 2006; Goswami 2006) showed that balanced application of NPK topped with farmyard manure treatment improved SQI. Remarkably, the ratings were significantly higher than those obtained by balanced application of NPK alone. On an overall basis, it appears that integrated nutrient management and supply systems need propagation for promoting sustainable farm intensification. Conservation agriculture espousing minimum tillage, legume catch crop and mulching jointly with precision agricultural practices is a way forward to attain high values of soil health indices.

Ancient Soil Management: Dictum Sustain Native Soil Health

Growth and development of *Homo sapiens* has moved with the availability of food. They tended to concentrate in regions endowed with enough supply/sources of food. For sustenance, early man started with hunting. As his numbers swelled, hunting was, perhaps, found wanting to maintain an uninterrupted nourishment. He then searched for more sustainable sources to fill his needs. Thus, began the consumption of plants and their produce along with game. Called ‘hunter-gatherer’ system, it widened the scope, range and longevity of food availability. Still it was inadequate, particularly when prey was beyond reach and food plants were destroyed by some natural adversary. This uncertainty gave birth to domestication of both animals and plants. This 12,000 to 10,000 year old episode marked the beginning of agriculture, albeit in the form of integrated farming. With time, it paved the way for permanent human settlements in areas endowed with good soils and water supply. This development brought man closer to soil followed by an everlasting interaction and union thereafter. At that point in time, the land was tilled with very simple tools. These primitive implements caused minimum disturbance to native soil integrity. In the present day parlance, this was equivalent of 'no-till' or 'zero-till' farming.

By and by, man realized sensitivity of soil productivity to constant cultivation. Accordingly, he moved agriculture from one place to another after a few years of cropping. The fallow period provided time for previously farmed soil to rejuvenate lost fertility. The growing needs for food were, hence, met with area expansion by opening up untilled lands. It was a kind of farming, 'the nature's way' with emphasis on least damage to inherent productive capacity of the soil and other natural resources. In the olden times 5 signature practices that helped sustaining food production comprised; (i) fallowing, (ii) soil conserving engineering works (terracing), (iii) cattle manure, (iv) crop residue composting and turn over and (v) legume as part of mixed cropping and a catch crop in-between two cereal crops. As a group, these practices constitute what is called 'ecological farming'.

Ancient agriculture was stable, albeit had limited yielding ability. It was, no doubt, in harmony with the environment, since non-exploitive way of farming disallowed overstepping limits of carrying capacity set by the nature. Area expansion scheme of farming remained relevant as long as land was more and the pressure of population was less. With time, however, low productivity systems lost significance in view of the growth in population density, rising demand for food, emerging economic compulsions and imposition of land ownership regulations. These developments knocked out the old area-extensive practices making way for the new high intensity soil farming methods. How this shift influenced soil health/quality in extent, economic loss and environmental degradation is narrated in the next section.

Green Revolution – Duality of Food Security and Soil Health Breakdown

Designed to save land by promoting growth in productivity, modern high intensity farming, invoked energy-dense practices. These constituted a combined input of modern dwarf varieties, fertilizers, irrigation, mechanization and precise agro-techniques. This shift proved a boon favouring unprecedented advance in low yielding ancient way of farming. Cereal grain production, which constitutes more than 90% of the total food grain production exploded (Figure 2). This transformation was specifically led by surge in productivity (Figure 3). Relative share of its contribution to growth in production compared to that of area expansion is cited as evidence (Figure 4). In 1967, William Doug of the USA named this development 'Green Revolution' (GR) of agriculture. Its happening eliminated the scourge of hunger from several food-insecure countries of the world, with India being in the forefront. For instance, the nation that was painted to die under the weight of food scarcity by a horde of Malthusian enthusiasts is an outstanding beneficiary of the GR. Just during the first 20 years of GR (1967-1986), India's rice plus wheat

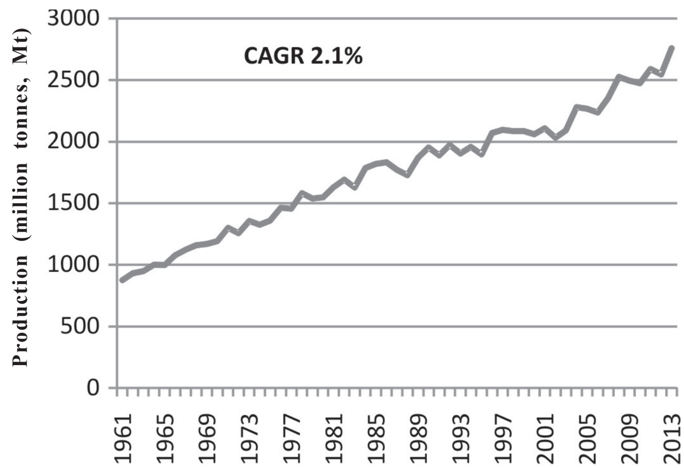


Figure 2. Global cereal production
Source: FAOSTAT (2015)

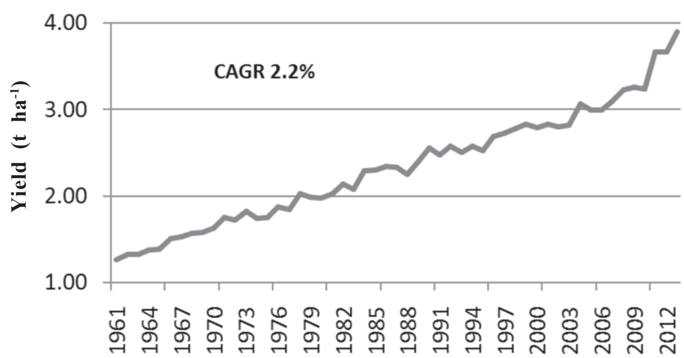


Figure 3. Global cereal yield (t ha^{-1})
Source: FAOSTAT (2015)

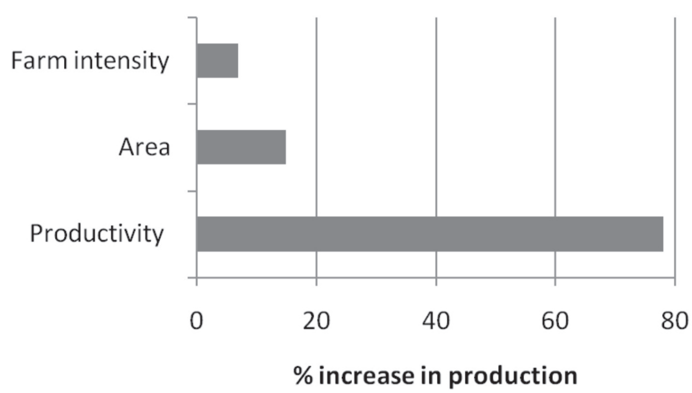


Figure 4. Elements of Green Revolution
Source: Nellemann *et al.* (2009)

production rose more than 100% (54.1 Mt vs. 110.8 Mt) (GOI 2014). Then there was no looking back from the point of growth in output of these and several other food grain crops (Katyal 2015). Undoubtedly, this unparallel success on the global food grain front lasted for 25 to 30 years, following which the productivity growth rates on which production was built showed signs of weakening (Figure 5). Compound annual growth rates (CAGR) in food grain productivity following the peak values reached up to 1990, plummeted sharply thereafter. This debacle was common across continents (Figure 6). Typically, Asia, where the advent of GR was the earliest, seemed to suffer the maximum from the productivity growth fiasco. Since input use continued to rise, yield growth fall was an indication on inability of the soil to support its innate or acquired productivity potential.

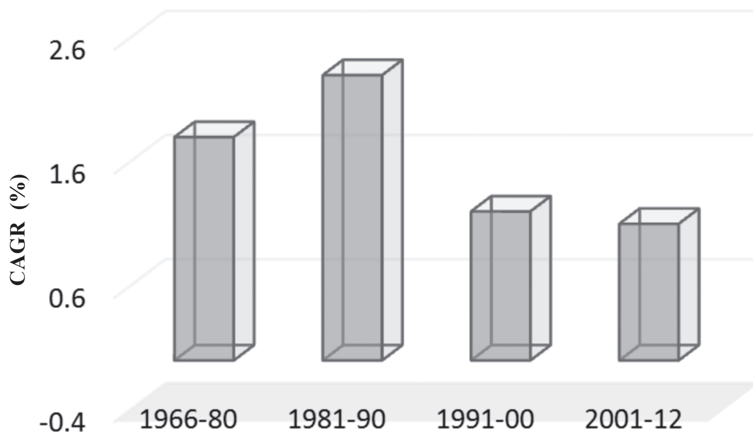
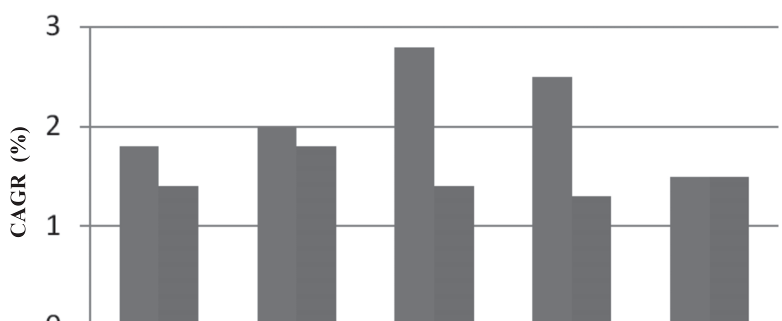


Figure 5. Progressive CAGR of cereal productivity
Source: FAOSTAT (2014)



	Africa	Americas	Asia	Europe	Oceania
1961-90	1.8	2	2.8	2.5	1.5
1991-12	1.4	1.8	1.4	1.3	1.5

Figure 6. Productivity growth rates of cereal productivity

The cause could be falling soil health due to disturbance in some physical (*e.g.*, soil structure and integrity), chemical (*e.g.*, fertility, salinity and pollution) and biological (*e.g.*, soil organic carbon, stability of microbial biomass, soil respiration and N mineralization) properties. Apart from yield growth decline, falling soil quality signalled a setback to normal functioning of a soil in delivering its bonded ecological services like acting as a sink for carbon (C) and regulating thereby barograph of climate change (Figure 7). During the last 50 years, 27% increase in atmospheric carbon-di-oxide load (and increase in other greenhouse gas emissions also) was accompanied by almost 1 °C rise in global temperatures.

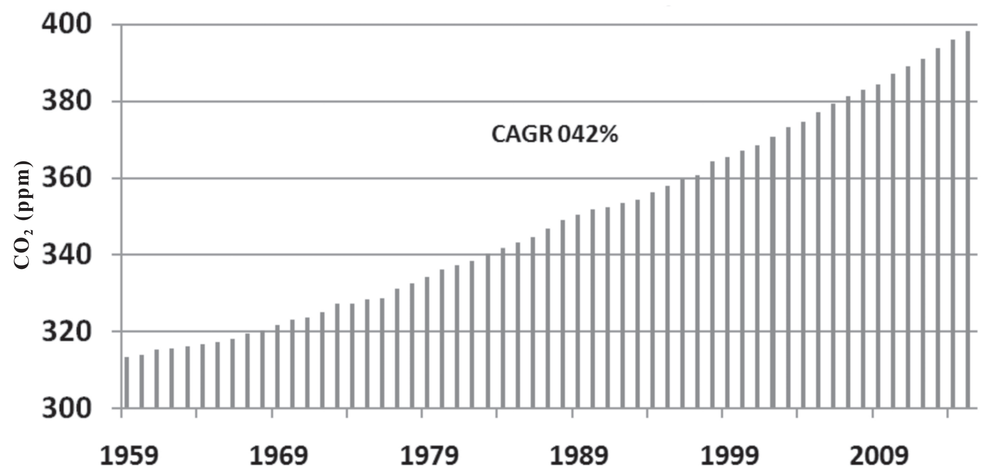


Figure 7. Motion in CO_2 (http://www.carbonify.com/carbon-dioxide-levels.htm)

Signals of falling soil health: In the ancient times, as long as area expansion was the means of increasing production, a soil's inherent functions of crop production and climate regulation remained intact. Once the man began exploitation by exhaustive use of soil by overstepping its native carrying capacity without appropriate restorer management, it started weakening its indigenous biodiversity, native fertility and sustenance of original soil organic carbon (SOC) reserves. In fact, inpristine era, farmers were able to maintain SOC and, hence, could prevent loss in soil biota and fertility by manuring, infusion of crops that add to fertility (*e.g.*, legumes), abandoning agriculture allowing time to regain lost fertility and by minimum disturbance to soil by accomplishing sowing and planting of crops by simple non-invasive tools. But modern energy-dense farming replaced these ecologically sound practices with fertilizers, exhaustive tillage with heavy machinery and closely spaced cereal-cereal rotations. This shift cut short the time for soils to rejuvenate and consequently degradation started insidiously making inroads into soil quality.

Loss of SOC, whose sustenance has profound influence on the health of soil and environment, is cited as an example. Rozanov *et al.* (1990) reported that world soils on average lost ~25 Mt SOC yr^{-1} since the dawn of agriculture 10,000 to 12,000 years ago. However, these losses were an average of 300 Mt yr^{-1} in the last 300 years and 760 Mt yr^{-}

[1] in the past 50 years. Rising impoverishment of SOC appears to correlate well with the recent fall in crop productivity growth rates (Figures 5 and 6). Then expansion in cropped area at the cost of destruction of vegetation (deforestation) inspiring global warming further amplified the weakening of native SOC reserves. Coinciding with this period, world experienced about 100% growth in population, 25% rise in crop land, 33% fall in forest and woodlands, 28% increase in CO_2 emissions and 25% loss of world's topsoil (Harrison *et al.*1993 and some other sources). During the same period, crop diversity index fell significantly. For instance, before the introduction of dwarf rice varieties in 1964-65, Indian farmers were cultivating 30,000 rice types, which tumbled to just 50 in 2005. Apart from SOC, fertility and biodiversity fiasco, man's modern managementmaking soil excessively wet (water logged), hot, polluted with harmful chemicals, acidic and salty are the other developments linked to saga of surging food production and escalating ecological losses.

These anthropogenic instigations came to fore no sooner did the quest to raise production for meeting the needs of ever-expanding population became necessary and the avenues for area expansion got closed. With nearly stagnating cropped area, more specifically, after 1990s (Figure 8), production growth has to be built around productivity increase. This, in turn, triggered further induction of intensive soil farming technologies. GR practices like: use of input responsive narrow genetic base varieties, closely spaced cereal-cereal rotations, extensive tillage/fire to clear fields of stubbles in preparation for the next crop, fertilizers, pesticides and irrigation continue to amplify intensive soil farming. As long as productivity increases happens by containing adverse rise of environmental outputs, intensive farming remains sustainable. Contrarily, the evidence shows that push to productivity growth was un-proportionally emphasized and consequences of doing that were blatantly ignored. Influence of this unbalanced management accelerated degradation in quality of soil and environment. This became evident with the lessening of

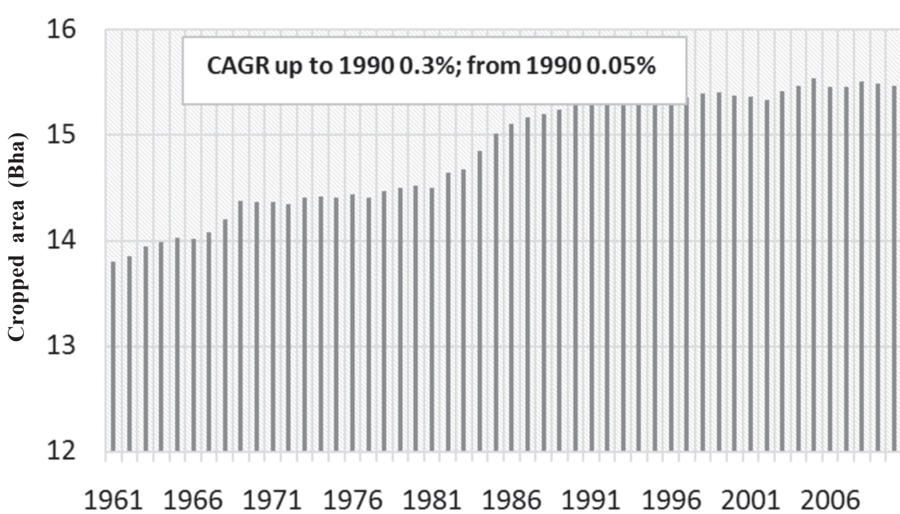


Figure 8. Global cropped area, Bha
Source: FAOSTAT (2014)

factor productivity (Figure 9) and agronomic efficiency of fertilizers (Katyal 2015). This, in turn, hurt productivity growth rates, despite consistent drive to press on modern inputs and interventions without restorer management. Hence, in order to remain food self-sufficient and environmentally secure, it is fundamental to protect and conserve health/quality imparting attributes of a soil from processes of degradation. This dictate, it is reiterated, cannot be dumped any more, since cropped area is limited and chances to expand it further nearly bleak.

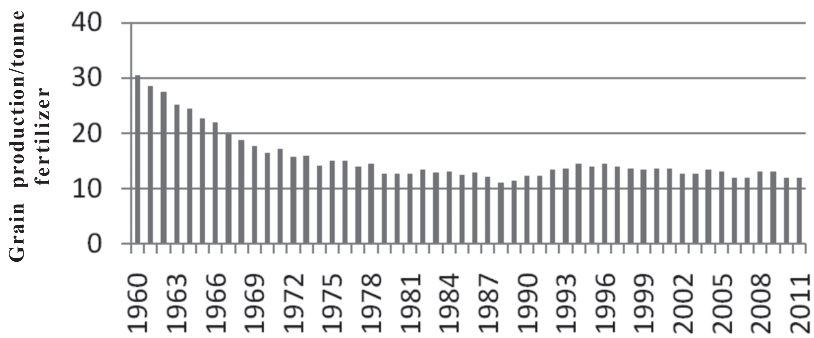


Figure 9. Food grain production/tonne fertilizer
Source: www.earthpolicy.org. and other sources

Soil Health - Causes of Deterioration

By now, it has become amply clear that it is the management-mediated interaction of user community with soils that is primarily responsible for enhancing or upsetting quality of soils in the recent times. Of all the organisms dependent on soils for their survival, humans and their animal support system assert maximum pressure on soil health. Firstly, soil has a finite space to accommodate a certain number of needy mortals. This is called carrying capacity. If the carrying capacity is transgressed consistently, soil quality declines due to overburdening. Since population number has already hit the wall, typically in developing countries, it is more urgent now than ever before to save soils from ongoing deterioration in soil health. Business as usual approach will only heighten environmental crisis costing 5-25% drop in current crop yields (Nellemann *et al.* 2009). Secondly, mismatches of land use and land attributes amplify processes of degradation. Thirdly restorative management espousing concentration on application of modern inputs of right kind, in right amounts, at right time and at right place in consonance with native sources and knowledge, can negate the adverse effects of exploitation by human numbers and land misuse. Having limited capability to invest in rebuilding the lost fertility due to excessive soil mining and depleted biodiversity due to knocking out of native land races, small and marginal farmers the world over are doomed to abuse their limited farm lands; often ending up by inflicting damage to the quality of soils and environment. On the contrary, large farmers enjoying luxury of input use, seldom worry for utilizing them efficiently. Wasteful input use, in several ways, breeds soil health problems. Example, overuse of agrochemicals leaves their large residual quantities in soil, which destroy useful soil biota leading to impairment of soil health.

As narrated earlier, maximum damage to soil began happening after 1960s. This was the time when due to advent of GR, world could overcome the curse of food insecurity from several food risky parts of the world. This also is the period when maximum concern on human actions destroying the quality of the very resource - soil (and water) on which their food self-sufficiency was built. Following ten events that promoted soil health degradation inspiring non-sustainable growth of agriculture are listed below.

1. Population: During the last 50 years, due to growth in population (from 3 to 6.9 M), per capita food grain area has become less than half (Figure 10). A clear indication that soils have to be exploited beyond carrying capacity to feed the proliferating human numbers. Typically, in developing countries where population pressure is high and proportion of nutrient stress-free soils is low, native fertility is being mined more than it is being renewed. Since 1960, only 3% of the soils, world-wide, are placed in fertile category.

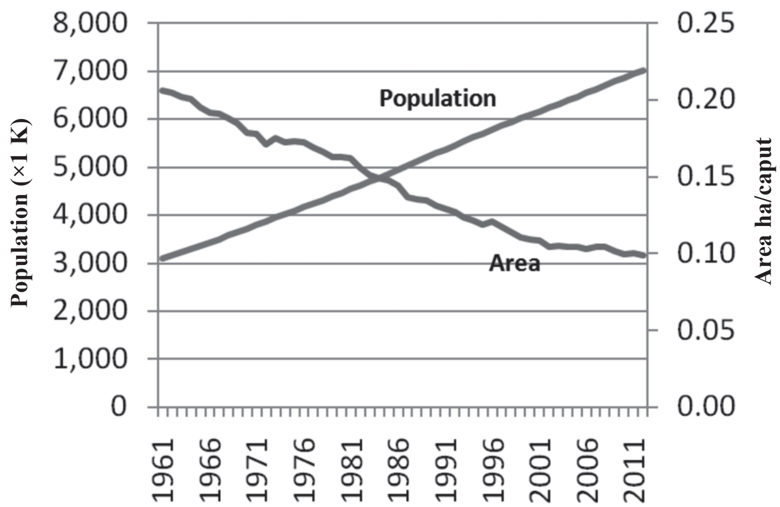


Figure 10. Population and food grain area ha/caput
Source: UN 2014 and other sources

2. Deforestation: Since1958 until 2015, global forest area shrank from 4.4 Bha to ~4 Bha; an average net annual loss of 7 Mha. Deforestation continues (Figure 11) to create land for cropping and provide wood for cooking and industrial uses. When forests are lost, the sink for atmospheric CO_2 stands eliminated. Globally, deforestation is the second largest contributor of CO_2 load to atmosphere - range 6-17% (Van Der Werf *et al.* 2009). Forest cover prevents erosion, helps soaking precipitation, building soil fertility, biology and physical condition.

3. Land use shifts: Transfer of ecological secure lands to cropped area (Figure 12) by removal and/or burning escalates incidence of adverse effects on soil's health and its climate regulatory function. Ongoing transfer of prime agricultural land in the vicinity of urban areas to fill the needs of industrial and infrastructure projects is another source worsening soil and environmental crisis. It happens, since what fills the void created by

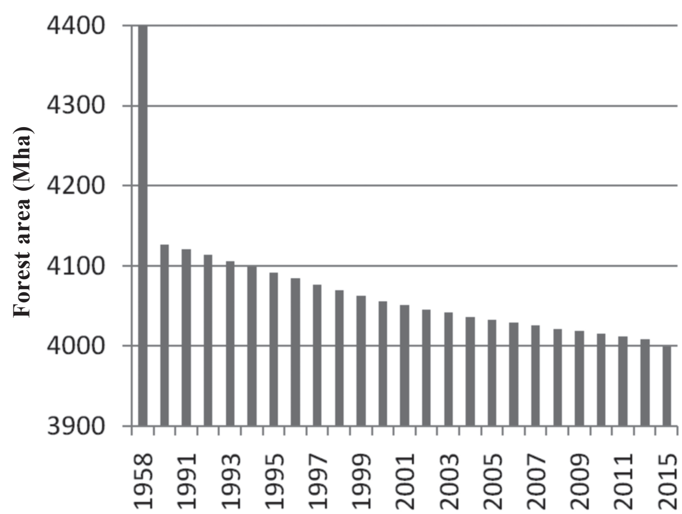


Figure 11. Global forest area
Source: FAOSTAT 2015+other reports

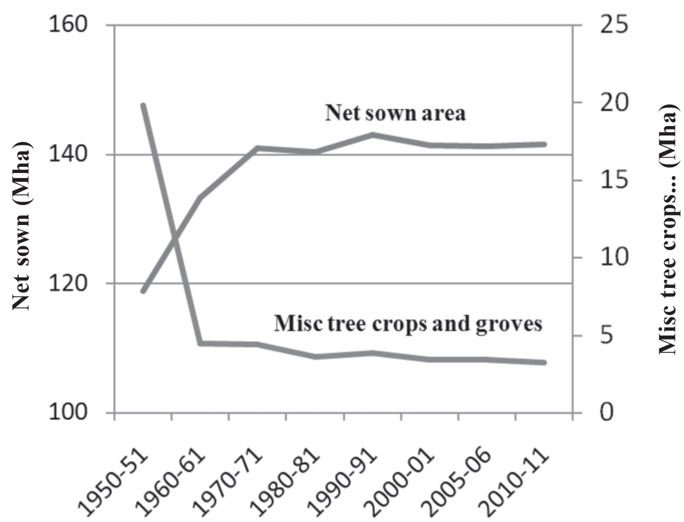


Figure 12. Shifts in net sown and misc. tree crops and groves area in India
Source: GOI (2014)

Note: Since 1950, ~22 M ha has been added to net sown area. Of this 17 Mha seems to have been contributed by destroying the ecological haven – 'Miscellaneous tree crops and groves' land use category
Source: GOI (2014)

this shift mostly belongs to wasteland category. Conversions of this kind have been happening swiftly across China and India over the last 50 years (Bongaarts 1998). Despite well-known adverse consequences of razing vegetative cover and moving good agricultural lands for other uses on soil and environmental health, these land use shifts proliferate across population dense intensively farmed regions of the world. FAO (1976) observed that land use changes that are at odds with sustaining vegetative cover or utilizing unsuitable soils for farming spur incidence of land degradation processes.

4. Intensive soil farming involves back to back cropping, requiring exhaustive tillage replacing 'nature's way of farming'. It has an excruciating influence on SOC by breaking it down to CO_2 (Lal 1999). Diminished level of SOC (Figure 13) also adversely affects fertility and soil physical condition. Falling use of organic manures and cereal-cereal cropping and knocking out the intervening catch crop are other elements decreasing SOC and deteriorating soil health.

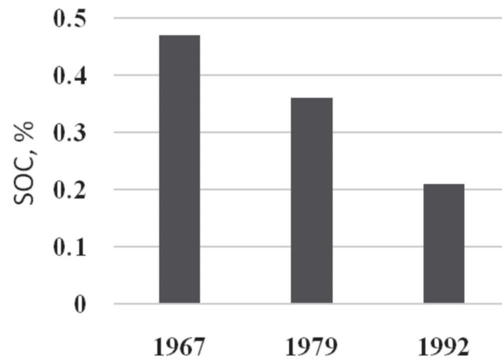


Figure 13. Changes in SOC in an Entisol (Pearl millet-wheat rotation)
Source: Antil *et al.* (2011)

5. High yielding varieties (HYVs): Farming with a handful of HYV is the source of near annihilation of their ancestor land races (Figure 14). As narrated earlier, before mid-1960s, Indian farmers cultivated some 30,000 rice types; today they plant just 50. This move heightened vulnerability of new varieties to new abiotic stresses (trace-element hunger) and rise of previously unfamiliar biotic (pests) disorders. Latter, typically, spiralled pesticide use; residues of which hit hard the sustenance of useful soil biota and soil health (details follow).

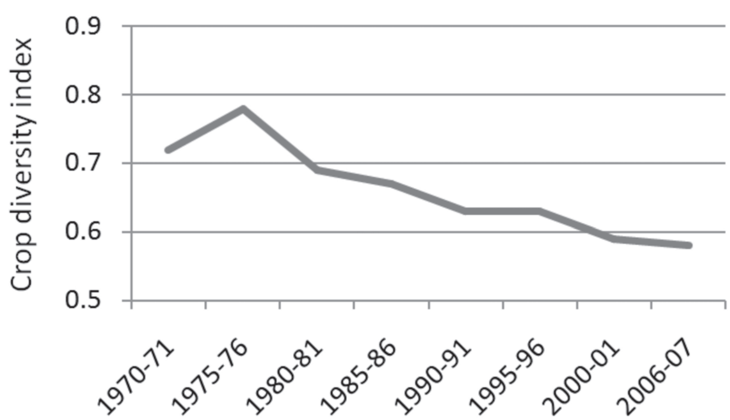


Figure 14. Crop diversity index (CDI), Punjab, India
Source: Sidhu *et al.* (2010)

6. Expanding application of fertilizers: While fertilizers have been harbinger of GR, they also are alleged to cause fall in soil health and climate change. Available information does not prove if fertilizer use has any direct link to the ongoing mess up in soil health or global warming (Bijay-Singh and Ryan 2015). What emerges is their continuing inefficient use (Table 3) that provokes rise of multi-nutrient deficiencies, contamination of ground waters, eutrophication of lakes and global warming (Katyal 2015). Non-holistic fertilizer management excluding the use of organic manures further accentuates the processes of soil quality degradation.

Table 3. Current state of fertilizer nutrient use efficiency (%)*

Nutrient	Use efficiency
Nitrogen	30-50
Phosphorus	10-20
Potassium	< 80
Zinc	2-5
Iron	1-2
Manganese	1-2
Copper	1-2

*Data from several sources

7. Mounting use of pesticides: Agricultural intensification favours pest survival and their continuing aggression. Also, cultivation of a few HYVs provoked rise of dormant pests (refer to an earlier section). Either way the pesticide use climbed several steps compared to that before GR (Figure 15). Since only 1% of the applied pesticide strikes the target, residues left in soil influence natural nutrient cycles due to deadening effect on soil biota. Loss of soil biology, hits organic matter dynamics, soil and water conservation, soil fertility and maintenance of air and food quality. Aggression of pesticides continues, because of weakened extension on promoting efficient and judicious use of pesticides.

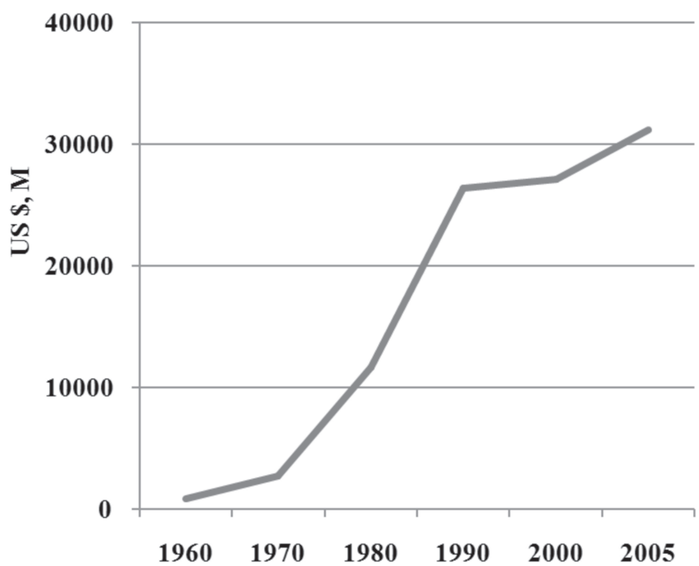


Figure 15. World consumption of pesticides (Value in sales)
Source: Zhang *et al*. (2011)

8. Irrigation: Like fertilizers, irrigation is necessary to realize the productivity potential of HYVs. However, continuing poor water use efficiency (<50%) of canal water affects soil health due to rise in salinity and waterlogging. Observed Qadir *et al*. (2014), "Every day for more than 20 years, an average of 2,000 hectares of irrigated land in arid and semi-arid areas across 75 countries have been degraded by salts". Then, overdevelopment of underground water (withdrawals exceeding recharge) is common across length and breadth of the world (Frankel 2015). It promotes mindless extraction that forces deepening of tube-wells (Figure16) and resultant rise in salt concentration of depleted aquifers. Irrigation with saline waters intensifies development of soil salinity. If the ongoing unprecedented rates of extraction are not slowed down and more importantly backstopped by effective rainwater conservation recharge, more and more world soils will become victim of further land degradation.

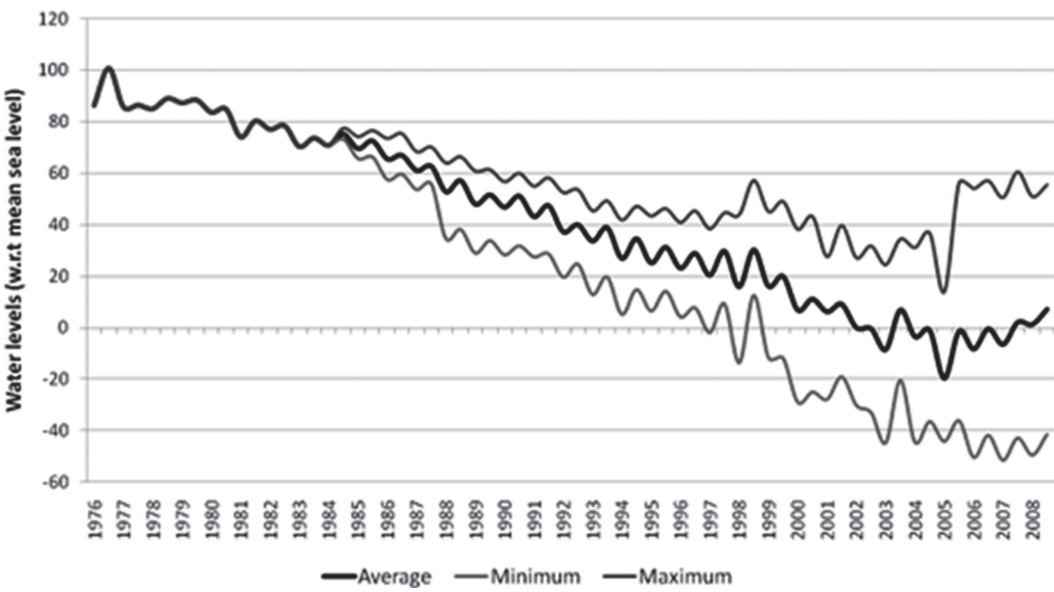


Figure 16. Declining water tables in Gujarat (270 cm yr^{-1})
Source: http://water.columbia.edu/research

9. Switching over to fossil fuel energy: With increased farm intensification, agriculture has become more and more industrialized. Its reliance on fossil fuel energy for powering machinery and manufacture of agro-chemicals has replaced manual labour and draft animals. With that allocation of fossil fuel energy for use of agriculture has increased faster in the core GR regions of the world *e.g.*, like India. Not only is the rate of increase, but the share of agriculture of the total energy produced and consumed has also risen sharply. Supply of heavily subsidized power is the push factor. For instance, respectively, India and USA employ ~25% and ~6% of the total energy for agriculture. Heavy subsidy on power to Indian famers is not the core issue, but it is the free energy that instigates its misuse; it is a matter of grave concern. According to Jha *et al.* (2012), ~50% of the

Table 4. Energy efficiency in different maize production systems

Agricultural system	Energy output/ input ratio
Slash and burn	8.4:1
Draught animal	4.1:1
Agro-forestry	4.1:1
Industrialized maize	2.8:1
Improved sustainability intensive maize like CA	4.8:1

Source: Pimentel and Pimentel (2012) Energy use in agriculture (http://www.agriculturesnetwork.org/)

energy allocated for agriculture is consumed by 23 million electric/diesel pump sets having energy use efficiency of no more than 30%. Likewise, of ~30% energy appropriated for manufacture of fertilizers, at least one half of that stands unutilized (use efficiency of fertilizer-N seldom exceeds 50%). Calculations of Pimentel and Pimentel (2012) confirm inefficiency of energy use by highly mechanized industrial agriculture compared to traditional or sustainable modern system of farming (Table 4). Antecedent waste in energy is released into the atmosphere as CO and CO_2. Resultant global warming influences soil health due to accelerated breakdown of active pool of SOC - nucleus of good soil health.

10. Modern intensive soil management practices and extension: A robust technology transfer (TT) system played a game changer's role in happening of GR. But over the years, public TT apparatus seems to have lost direction. This debacle is led by an exclusive focus on productivity push at the cost of turning a nelson's eye to results of doing that. Also, the existing TT system engages itself more in distributing subsidized inputs and devotes less time advising their proper management. As is well known, efficient use of low cost inputs is subject to question. With that what emerges is greater likelihood of overuse, misuse and unbalanced use. In fact, such are the reports. For instance, farmers over-apply cheaply priced N fertilizers exceeding crops requirements. Simultaneously, they ignore necessary application of P and K, which are relatively more expensive. This scheme of management gives rise to imbalanced nutrition and fall in use efficiency of N, P and K fertilizers (Table 3). Then unequal emphasis on subsidized power and pumps for lifting ground water for irrigation promotes energy wastage. In striking contrast to enhance fertilizer use, TT agents give lukewarm treatment to application of organic manures. Fueled by imperfect prominence to holistic input and soil management practices, incidence of multi-nutrient deficiencies, encroachment of salinity, SOC decline, pollution of soil, water and air, fall in soil physical health and biological wealth and rise of climate change galore in extent and intensity. On an overall basis, these hostile developments add to deterioration in health of soils and environment. Rise of these adversaries explains the weakening of input-factor productivity (Figure 9). This in turn reduces the value of output due to inferior input response. All this happens because of non-sustainable intensive farming practices promoting decay in soil health indicators (loss of nutrients, overuse of water and inefficient management of pesticides) (Table 5).

Table 5. Environmental costs of some on-site effects from conventional intensive agriculture

Item	Cost (US \$) ha^{-1} yr^{-1}
Loss of soil nutrients (leaching)	113.00
Loss of water (over and misuse)	50.00
Pesticide impacts (inefficient use)	25.00
Total	188.00

Source: Pimentel (1993)

State of Global Soil Health

As stated earlier in this report, pursuance of necessary production goals from falling share of cropped area/person (Figure 10) was made possible by farm intensification. The record, however, shows that intensification up till now has followed non-sustainable soil management practices. For instance, the aftermath of over-mining of soil resources without restorer management has shown up in the form of falling quality of soils, declining water resources, depleting biodiversity and climate change. Rise of these adverse events points to growth of expanding land degradation, which, is known antonymous of good soil health. Despite treatment with requisite GR inputs, a degraded soil is unable to sustain productivity growth and perform its innate function of maintaining environmental security. Due to persisting deficit of knowledge and resources on sustainable soil management practices, small and marginal farmers world-over are unable to replenish lost fertility, extracted water, plundered vegetation and depleted biodiversity. Resultantly, since the happening of GR, conventional soil management has hit the soil health hard with costs (Table 5).

United Nations Environmental Program (UNEP) has estimated that during the 2nd half of the 20th century, world compromised quality of ~2 Bha farmland to degradation (Oldeman *et al.* 1990) and experienced a population rise of 4 billion (B). The problem does not stop here, since every year 2 to 5 Mha new degraded land is added to this category (Nellemann *et al.* 2009). This translates into a loss of nearly 10 ha good land/ minute to various processes of degradation. The International Food Policy Research Institute (IFPRI 2011) assessed that about 1 out of 4 ha of total global land area (14.8 Bha) has been affected by ruinous acts of man; non-holistic soil management occupies the central place. In terms of food grain production, land degradation transmutes an annual loss of 20 Mt or 1 per cent of the global annual food grain production (2201 Mt in 2010, FAOSTAT) (IFPRI 2011). Worldwide, 1.5 B people and 42% of the very poor live on degraded lands. Share of India in global degraded soil area is about 10% and of population is 17%. With ongoing pressure of feeding burgeoning population, typically when the human numbers have reached a tipping point in developing countries, it has become more imperative now than ever before to protect and preserve quality of soil resource to sustainably build productivity growth. Since onslaught on soil quality, more than nature, is the act of all stakeholders - farmers, builders and common folks, they have to be part and parcel of the protection and conservation programs also. Globally, 500 M small and marginal farmers out of a total of 525 M, are the largest interest group of agricultural land (~1.5 Bha). Accordingly their role in sustainable soil management is of the top most significance.

Soil health, as in several other countries of the developing world, is relatively a greater threat to Africa's and South Asia's sustainable growth of agriculture and food security. Weak soil rejuvenating policies have not measured up to the expectations in addressing and managing soil health concerns (http://www.wfp.org/hunger/stats). As a consequence, majority of the African nations are faced with serious soil health challenges. Some 75% of the agricultural soils have been significantly degraded. As an aftermath of that over half of the production zones suffer from grim fertility problems (Jones 2006).

Then more than 80% of the soils exhibit chemical or physical limitations that constrain crop production (AGRA 2013). These soil challenges are being exacerbated by additional threats such as transgression of soil's carrying capacity and extreme weather events. The World Bank has predicted that rainfall patterns in sub-Saharan Africa will shift, acute heat events will occur more frequently and dry arid regions will expand in extent. Consequently, African farmers are expected to see lower crop yields, lose arable land (from 40–80% of the croplands that grow maize, millet, and sorghum by some estimates), and will have less food available for consumption (World Bank). These trends may be compounded by a population boom in the continent. Africa's population is estimated to quadruple within next 90 years (The Washington Post 2013). In fact, success of GR seems to have been marred more by the lack of seriousness on reclaiming weathered degraded soils than application of modern yield enhancing technologies.

Poor condition of soil health in Asia is equally widespread. Nearly, 1 out of 3 hectares of global degraded lands (370 Mha out of a total of 1035 Mha, UNEP 1992) are found in Asia. Erosion (82%) as well as physical and chemical processes (18%) is the main soil health constraints that adversely influence crop productivity and sustainable growth of agriculture. In South Asia alone, respectively 83 and 59 Mha have been degraded by water and wind erosion, says an FAO Report (FAO 1994).India houses some 105 Mha of degraded farm land out of a total of 142 Mha net sown area (NAAS 2010). Here also loss of soil health due to erosion is maximum – 85.7 Mha (water erosion 73.3 Mha and wind erosion 12.4 Mha).

Extent of Economic Losses

Globally, soil health decline causes serious economic and environmental damages. Economic costing is done by possible output loss in agricultural production utilizing production value of healthy soils as the benchmark. Additionally, monetary value is also reckoned by working out the cost of replacing lost nutrients (by fertilizers) and requisite investment made for land reclamation and restoration. Compared to estimating value of land degradation, monetary loss of environmental deterioration are difficult to assess. A few selected studies on economic losses attributable to soil health are cited as example.

As is well-known, soil erosion poses maximum threat to productive capacity of soils and sustainability of agriculture. World-wide, 1642 Mha is affected by erosion, both by wind and water. While former concentrates its ruinous act in arid and semi-arid regions, the latter's effect is ubiquitous. According to Pimmentel *et al.* (1995), over the last 40 years nearly one third of the world's arable land is lost to erosion. More disturbing is the fact that it continues to spread at a rate of more than 10 Mha yr^{-1}. On a global scale, Africa and Asia are the biggest victims of soil erosion. South Asia alone, according to a study sponsored by FAO, UNDP and UNEP (FAO 1994), suffers a monetary loss of ~US $ 10 B due to various processes of land degradation (Table 6).

In Sub-Saharan Africa, the value of lost fertility is far more severe. There each hectare annually stands to be robed of 22 kg N, 3 kg P and 15 kg K (Lal 1998). World-wide, not only nutrients, eroded soils also get depleted of their native water stocking

Table 6. Cost of land degradation in S. Asia

Process of degradation	Economic cost (US$ B)	Remarks
Water erosion	5.4	Equivalent to 2% of the region's GDP, or 7% value of agricultural output.
Wind erosion	1.8	
Fertility decline	0.6-1.2	
Water logging	0.5	
Salinization	1.5	
Total	9.8-10.4	

Source: FAO (1994)

capacity. Consequently, each tonne of soil runoff costs US$ 5 due to nutrient (US$ 3) and water holding capacity (US$ 2) loss. Annual global misplacement of 75 billion tonnes (Bt) of soil is valued at about US$ 400 B yr^{-1}; equivalent to US$ 70 capita yr^{-1} (Lal 1998). Share of India in this plunder equals US$ 26 B on the basis of an annual soil loss of 5250 Mt (Dhruva Narayana and Ram Babu 1983). So severe is the influence of erosion that just 3% of the world soils are free from its menace. These prime or Land Capability Class (LCC) I lands are not part of the tropical regions. Further, only 8% of the land area belongs to LCC II and III. Thus, globally 11% of the agriculturally suitable lands have major responsibility of feeding ~ 7.2 B people now and some 9.2 B in 2050. Land degradation in dry lands (arid, semiarid and dry sub-humid tracts), called desertification, is experienced on 33% of the total land area and affects more than one billion humans, half of whom live in Africa. In India, Sharda and Dogra (2013) estimated an annual loss of 13.5% in food grain production of drylands due to water erosion alone. This damage has a price tag of~US$ 4 B. Furthermore, despite implementation of best possible soil and water conservation programs in a developed nation like US, annual monetary loss due to soil erosion is valued at a staggering sum of US$ 44 billion or US$ 247 ha^{-1} of crop and pasture lands.

Salinity is another global soil health concern. It costs a damage of US$ 27.3 B yr^{-1} (Qadir *et al.* 2014). All this happens due to faulty drainage management of irrigated lands. In India, currently excess salts influence productivity of some 6.7 Mha (Mandal *et al.* 2010), which is equivalent to about 5% of the net sown area. On the basis of very conservative estimates (on 5% production loss basis), it sums up to about 12 Mt of food grains, valued at nearly US$ 900 M/annum. Until effective, even if extreme, policy measures are not imposed to enhance use efficiency of surface waters and containing overdevelopment of underground waters, sustainable amelioration of salinized soils will remain under a cloud. Incidentally, it is already being realized that reclaimed soils may again be faced with the same problem. This is predicted to happen if leached sodium + salts, before mingling with the underground water are not pumped out to a safe destination. If allowed to reach the already stressed underground water, the seeped chemicals will resurface rendering the reclamation investment infructuous.

Soil fertility loss is another potential threat to sustainable development of agriculture of several countries of the developing world. Besides erosion, as narrated earlier, overdevelopment of nutrients – adding less and harvesting more, is another reason of depleting soil fertility. Adverse influence of impoverished fertility is, typically, more challenging for sustaining Africa's food security. Weak soil rejuvenating strategies have not been able to measure up to the expectations in addressing and managing soil fertility concerns (http://

www.wfp.org/hunger/stats). As a consequence, majority of the African countries are faced with grave soil health issues (details in an earlier section).

In addition to soil infertility and erosion, compaction (or deterioration in soil physical condition) is another global soil health problem. Its incidence has risen, especially with the adoption of mechanized agriculture. It has caused yield reductions of 25 to 50% in some regions of Europe (Eriksson *et al.*1974) and North America, and between 40 and 90% in West African countries (Charreau 1972; Kayombo and Lal 1994). In Ohio, reductions in crop yields are: 25% in maize, 20% in soybeans and 30% in oats over a seven year period (Lal 1996). On-farm production losses attributed to compaction in the USA have been estimated to cost US$ 1.2 B yr^{-1} (Gill 1971).

Summary and Way Forward

Soil health concept and consequence: Soil health is an assemblage of chemical, physical and biological parameters that closely relate to native or acquired production capacity and sustenance of ecologically important regulatory role. A soil is said to be suffering from ill health when it is unable to perform either of these functions. It happens when a soil is employed for a purpose for which it is not suitable or is managed poorly. In fact, soil health decline has been happening since time immemorial. What is new is the intensity of its aftermath that started building up a visible impact following the induction of GR technology and related inputs (fertilizers, pesticides, irrigation, fossil fuel energy...). The consequences appeared in the form of falling input factor productivity and climate change. There is no evidence to show that GR technology/inputs have any direct role in causing these adverse repercussions. In contrast, a body of information proves that it was the non-holistic soil and input management that dented the ability to sustain response to inputs and maintain quality of environment. By now it has become amply clear that soils become sick when imperfect management focusing singularly on productivity is imposed and curative interventions to contain the consequences of doing that are given a miss.

Measures of soil health: Soil health is measured against some predefined parametric chemical, physical and biological characteristics. Value of these properties describes a soil's state of fertility, compactability, erodibility and biology. Of these, chemical (pH, EC, nutrient availability...) and physical (BD, WHC...) properties are possible to routinely analyze and assess in the existing soil testing laboratories. Except SOC, biological parameters like labile (light C fraction) and non-labile (heavy C fraction) organic pools, soil respiration..., due to lack of facilities and expertise, are seldom evaluated. Then there is general lack of unanimity among soil scientists and microbiologists on common biological properties that describe soil health. Since soil health measurements spread across disciplines, there is an express need for convergence of goals and opinions to arrive at a common set of measurements describing soil health as an index. Based on past findings on soil health index, it is suggested that a small number of carefully chosen soil quality parameters, when integrated as a simple, non-linearly scored index, can adequately provide information needed for selection of best management practices.

Soil health – Epicentre is SOC: It is reiterated that mismanagement of sources and resources is the root cause of ongoing decay in soil health since 1960s. Overexploitation due to transgressed carrying capacity, destruction of ecological havens (deforestation), shift to non-sustainable intensive farming practices like, deep tillage, removal of crop residues, disuse of organic manures and elimination of legume catch and intercrops, inefficient handling of agro-chemicals, water and energy and weakened technology transfer system have contributed to degradation in quality of soils and other natural resources. Led by deteriorating SOC content, (i) rising vulnerability to erosion, (ii) diminution of native fertility and physical state of soils, (iii) loss of useful soil biology and (iii) growing emissions of CO_2 back into the atmosphere are the most disturbing outcomes of this man-made fiasco. In addition, mismanagement of surface waters and overdevelopment of underground aquifers, without regard for reclaiming withdrawals with rainwater conservation, present an unrelenting growth of soil salinity and water logging. These current and past wasteful handling of an entire set of native sources and synthetic inputs, besides soil health issues, has role in amplifying speed of climate change. Ongoing global warming, besides increasing the frequency of aberrant weather events, worsens a soil's ecological functions like native N, C and water cycles. Not only is the easily decomposable labile organic pool lost, but relatively stable soil humus, also breaks down during periods of excess rainfall (Song *et al.* 2012). Incidentally, humus constitutes the chief terrestrial C reservoir. Apparently, SOC is seen to become increasingly insecure with global warming and frequent incidence of pronounced precipitation events coming in its wake. The rundown product - CO_2 will further step up climate change (and soil health concerns). Significant also will be the contribution of rising emissions of other greenhouse gases - N_2O and CH_4. Poor management of N fertilizers and rice paddies provoke egression of these gases.

On all counts, SOC decline sets in motion a vicious cycle of events that spark alarm bells ringing on falling soil health. From an edaphological angle (understanding of soil properties that influence plant growth and production) following soil characteristics are hit the hardest:

- compaction - defines aeration, structure, bulk density, root penetration…,
- fertility – means ability to supply essential nutrients in sufficient amounts and right proportion needed for optimum crop growth,
- erodibility – describes vulnerability of a soil to lose valuable topsoil by water or wind erosion,
- soil biology – illustrates undisturbed state of native useful soil biology, which is responsible for mobilization of nutrients, sustenance of natural nutrient/water cycles and regulation of climate, and
- chemical composition - presented as state of harmful chemicals or excess availability of essential nutrients.

These attributes are the elements that define soil health/quality and in one or the other way are regulated by dynamics of SOC; decrease has a negative effect, the rise influences in a positive way. Maintaining soil in good health is associated directly with sustainable development of agriculture, *e.g.*, maintaining a tempo of productivity growth without need for unnecessary inputs or additional investments to sustain it. This also signals that a soil in good health ensures non-production of negative outputs like climate change or rise in contaminants and pollutants, assuring thereby sustainable growth of agriculture in all its aspects.

Soil health collapse – human actions hold the prime responsibility: Information collated and presented in this report confirms that withering quality of soil and environment are anthropogenic in origin. Man, therefore, has to commit, connect and become responsible for remedying these maladies also. Soil, which is neither dirt nor a commodity, has a filial allegiance to humankind as a community. True to the reverence shown towards soil in the olden times, it requires protection from mismanagement. Conservation and sustenance of soil quality has to become an integral element of public policy, which has to be compulsorily dedicated to sustainable economic and ecological development. Otherwise what Franklin D. Roosevelt, XXXII President, USA, said in 1937 "The nation that destroys its soils destroys itself", may come true. He went on to say, "The history of every nation is eventually written in which it cares for its soils" (www.presidency.ucsb.edu/ws/?pid=15373). Refrains sustaining good soil health call for more concerted effort now than any time before in the past. In pursuance of that need, it is suggested to strengthen, harmonize and apply a mix of 'relevant ancient good practices' and 'currently right inventions and interventions'. Accordingly, devised safeguards on conservation and enhancement in quality of soils have to be in the form of a holistic management scheme– a scheme that blends sustainable productivity growth and environmental security. In order this approach produces effective outcome, its application and adoption have to be a 'community-based area approach'. It is said so, since if some do not conserve and save soil from ruinous act of erosion, investment of many to preserve its quality will become worthless. To begin with, forging group-action will require mentoring with some pecuniary support. Public policy and R&D institutions, therefore, need to facilitate creation of strong community-based organizations. Must also, they establish a risk-proofing and risk-distributing infrastructure; strategy of which persists on soil health building societal knowledge and knowhow. Approach and methods (NRCS USDA 2016) on countering decay in soil quality are enlisted in a tabular form (Table 7). Various elements of this scheme, once adopted and practised will counter the rise of soil loss and soil health weakening processes. The infrastructure on risk-distribution calls for building farmers' resilience to climatic and market shocks by involving robust community-based agricultural insurance machinery. Success with both approaches will elude, if farmers' needs and aspirations are not included before the suggested technology package (Table 7) is introduced and/or a crop insurance scheme is launched. Making available necessary inputs constituting a technology package will hasten adoption of various elements of this risk-mitigating tactic. Likewise, offering of an inexpensive, hassle-free claim-assessment and settlement plan will widen acceptance of crop insurance and enhancing thereby adaptation to recurring farm-risks. An overarching prerequisite will be launching of appropriate non-formal and informal educational programs to prepare farmers' appreciation for rationale of applying conservation knowhow on holistic management of soils by efficient use of chemical sources and native resources on the one hand and acceptance of agricultural insurance on the other. In fact, adoption of right soil manage-

Table 7. Strategies of soil health management as per NRCS-USDA (2016)

Strategy	What does it do?	How does it help?
Conservation Crop Rotation Growing a diverse number of crops in a planned sequence in order to increase soil organic matter and biodiversity in the soil.	• Increases nutrient cycling • Manages plant pests (weeds, insects, and diseases) • Reduces sheet, rill, and wind erosion • Holds soil moisture • Adds diversity so soil microbes can thrive	• Improves nutrient use efficiency • Decreases use of pesticides • Improves water quality • Conserves water improves plant production
Cover Crop An un-harvested crop grown as part of planned rotation to provide conservation benefits to the soil.	• Increases soil organic matter • Prevents soil erosion • Conserves soil moisture • Increases nutrient cycling • Provides nitrogen for plant use • Suppresses weeds • Reduces compaction	• Improves crop production • Improves water quality • Conserves water • Improves nutrient use efficiency • Decreases use of pesticides • Improves water efficiency to crops
No Till A way of growing crops without disturbing the soil through tillage.	• Improves water holding capacity of soils • Increases organic matter • Reduces soil erosion • Reduces energy use • Decreases compaction	• Improves water efficiency • Conserves water • Improves crop production • Improves water quality • Saves renewable resources • Improves air quality • Increases productivity
Mulch Tillage Using tillage methods where the soil surface is disturbed but maintains a high level of crop residue on the surface.	• Reduces soil erosion from wind and rain • Increases soil moisture for plants • Reduces energy use • Increases soil organic matter	• Improves water quality • Conserves water • Saves renewable resources • Improves air quality • Improves crop production
Mulching Applying plant residues or other suitable materials to the soil surface to compensate for loss of residue due to excessive tillage.	• Reduces erosion from wind and rain • Moderates soil temperatures • Increases soil organic matter • Controls weeds • Conserves soil moisture • Reduces dust	• Improves water quality • Improves plant productivity • Increases crop production • Reduces pesticide usage • Conserves water • Improves air quality
Nutrient Management Managing soil nutrients to meet crop needs while minimizing the impact on the environment and the soil.	• Increases plant nutrient uptake • Improves the physical, chemical, and biological properties of the soil • Budgets, supplies, and conserves nutrients for plant production • Reduces odors and nitrogen emissions	• Improves water quality • Improves plant production • Improves air quality

Strategy	What does it do?	How does it help?
Pest Management Managing pests by following an ecological approach that promotes the growth of healthy plants with strong defenses, while increasing stress on pests and enhancing the habitat for beneficial organisms.	• Reduces pesticide risks to water quality • Reduces threat of chemicals entering the air • Decreases pesticide risk to pollinators and other beneficial organisms • Increases soil organic matter	• Improves water quality • Improves air quality • Increases plant pollination • Increases plant productivity

ment practices and efficient administration of agro-chemicals, water and energy lay foundations for inspiring C sequestration, building farm resilience/adaptability and mitigating climatic risks.

Sustainable soil health management calls for convergence and partnerships: In order to transform commitment of government's policy into effective and tangible results, a cornerstone of success will be convergence of research and development (R&D) activities. Gone is the era when each agency ploughing its lone furrow was able to register its presence. Time has come when performance audit is going to be the order of the day. For which to happen, union of programmes and institutions is necessary to remain efficient, relevant and contributing. In this pursuit, networking with farmers' groups right from the entry point of infusing education and training, technology development/transfer/refinement, application, monitoring, assessment and validation prefaces theirs' (i) say in prioritizing interventions – both educational and technical - before setting objectives, (ii) share in drawing action plan and indicators of success, (iii) ownership supporting implementation steps, (iv) willing preparedness for sustainable adoption, and (v) feedback on further refinement of an activity/technology package. Working hand in hand with farmers will not only cut short the lag period between right-technology development and dissemination, but will help re-establishing lost link between soil and farming community also. Joint working of scientists with development departments will perforce bring them out of their labs. Not only will convergence avoid duplication of efforts but will also add to quality of output in a most economical way. Further, partnership of public outfits with private agencies is a recognized arrangement of reshaping invention into innovation. Also, as previous record shows, private players remain valuable collaborators in technology transfer to the last delivery point. These pluralistic alliances are seen as different props nurturing an understanding on real life soil (field) problems and finding practicable solutions that are pro-farmer and pro-nature.

With farmers as the nucleus, convergence of public programmes and public-private partnerships are advancement on revitalizing technology transfer apparatus. It is also a way forward on jellying the scientific mindset and other stakeholders' perception espousing sustainable soil health. Since, conservation farming concept and modern techniques of farming work well together; merging their strengths will be part and parcel of the proposed institutional arrangements. Presumably, this plan will revive ancient reverence of human society treating soil as part of their 'community' (Prithvi Sukta, Atharva Veda 1000 BC; Leopold 1949) obligating man to take good care of soils.

At the end following action points are suggested to sustain and enhance soil health:

Research

- On the canvas of biophysical attributes of a location, strengthen research to clearly understand and underline quality management interventions that specifically help building soil biology and soil physical health. Accordingly, assembleappropriate measurements that are sensitive enough to capture near-time changes in physical and biological health. Soil scientists and soil microbiologists will need to team up to develop model indicators.
- Investigate influence of climate change on SOC dynamics and productivity changes across diverse production systems.
- Study time-bound build-up of SOC by protecting it from loss by introducing conservation management and diverse organic matter turn over practices
- Launch an investigation to assess extension gap (demonstration yield – farmers' yield) on adoption of soil health building technologies. To be conducted in tandem with a farmers' feedback investigation, this study will provide insight into constraints/misgivings, which farmers face on adopting interventions like conservation agriculture (CA), application of organic manures, efficient management, balanced use of inputs...

Development Research

- Develop tactics on maximizing return of various organic sources by evolving: (a) appropriate individual or community-based biogas units to replace dung as fuel, (b) legislative measures that are easy to implement and monitor, and difficult to evade and manipulate for forcing total ban on burning of vegetative materials of all kinds, (c) short duration multi-purpose varieties of legumes servingas catch crops in cereal-cereal rotations, (d) conservation agriculture system, (e) use of integrated soil and nutrient management and (f) a reward and incentive scheme for those who adopt (a) to (e). Without an appropriate policy instrument goal of year on year basis improvement in SOC is less likely to be achieved.

Development

- Facilitate increasing use of zero-till machines, alternative sources of energy (typically solar), efficient fertilizer applicators, and water lifting devices by eliminating supply deficit and strengthening initial support. Also assist those who simultaneously get laser levelled their fields and shun flood method of irrigation.
- Strengthen further support for rainwater conservation by bringing in its fold irrigated tracts also; the support should in particular be extended for minimizing runoff and maximizing groundwater recharge.

Policy

- Pronounce a policy to attain at least 0.04% per annum growth in soil organic matter content by banning destruction and encouraging use of organic manures of diverse shades on one hand and employing organic matter conservation management on the other.

- Re-look and re-evaluate fertilizer subsidy scheme by: (i) rationalizing differential pecuniary support for NPK fertilizers, and (ii) incentivizing those who save fertilizers by adopting efficient methods but without compromising needed sustainable growth in productivity.
- Reinvent power subsidy scheme on lifting water by assistance for adoption of efficient pumps and particularly those run by alternative source of energy (solar).
- Support dry granulation (compaction) for manufacture of site-specific fertilizer mixtures as a small scale industry.

Extension

- Induct and launch effective formal, non-formal and informal education and skill development programs to empower farmers with knowledge on location and situation specific holistic soil management programs.
- Reinvent a technology transfer system that strengthens its reach (a pluralistic set up) and effectivity (multi-functional) by nucleating around farmers and farming constraints.
- Spread use of ICT means to prepare a country-wide register on farms (soil health), farming (inputs and technology used) and farmer (socio-economic status) to assess location and situation specific needs on knowledge, knowhow and public support to be extended through technology transfer machinery.

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Soil Health in India: Retrospective and Perspective

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Soil is the essence of life on the planet Earth. It has sustained humanity and human civilizations through five functions (Karlen *et al*. 1997) *viz*., i) sustaining biological activity, diversity and productivity; ii) regulating and partitioning water and solute flow; iii) filtering, buffering, degrading, immobilizing and detoxifying organic and inorganic materials, including industrial and municipal byproducts and atmospheric decomposition; iv) storing and cycling nutrients and other elements within the earth's biosphere; and v) providing support to socioeconomic structures and protection for archaeological treasures associated with human habitation. Reeling under the pressure of increasing food, fodder, feed, fibre and fuel production, soil has been used as a medium of plant growth with considerable reliance on external supply of major nutrients, irrigation water, plant protection chemicals, etc. Although soil, a product of millions of years of weathering, has supported various forms of terrestrial life, its sustainable management holds the key for meeting the basic requirements of burgeoning population and development commitments. So intense has been the pressure of increasing food, fodder, feed, fibre and fuel production that the soil has been exploited often exceeding its carrying capacity. Resultantly the soils of various agro-ecological zones under intensive cultivation have developed fatigue as reflected in terms of declining total and partial factor productivity, plummeting response ratios and rise of other negative episodes. Adoption of inappropriate policies and cropping systems along with faulty soil management accelerated soil erosion, witnessed the aggrandized incidence of secondary- and micronutrient deficiencies, and impacted adversely the soil biodiversity and physical properties. As a consequence, 120 million hectares (Mha) of land in India got degraded in quality. Emerging events like climate change, diversion of productive agricultural lands to non-agricultural uses, faulty disposal of effluents and wastes from cities and industries, international commitments on controlling greenhouse gas (GHG) emissions, rising cost of fertilizers have further exacerbated the magnitude of the problem. India's population crossed the one billion mark by the turn of the 20th century. Pragmatic assessments reveal that to meet the food requirements of increasing population, India needs to increase its food production at the rate of 6 Mt yr^{-1}; a daunting task indeed. However, in view of the past achievements, and given the resilience of the system, there is no reason to think as to why this phenomenal acceleration cannot be achieved. Adoption of standard management practices along with appropriate application of inputs especially seeds, fertilizers and water would be the major determinant of future food growth. Among these, the most costly input would be nutrients (major and micronutrients), whose judicious and need-based use would trigger necessary growth of Indian agriculture in the coming decades.

With the adoption of the intensive agriculture production model during the last five decades, major crop-based production systems have started showing symptoms of decline. Conservative estimates show that the demand for food grains would increase from 257 Mt in 2012-13 to 355 Mt by 2030. Whereas, the food demand is on the increase, the factor productivity and rate of response of crops to applied fertilizers under intensive farming conditions are continuously declining with every passing year. Use efficiency of nutrients is abysmally low and nutrient-wise it is 30-50% for N, 15-20% for P, 60-70% for K, 8-12% for S, 2-5% for Zn, 1-2% for Fe and 1-2% for Cu. Major reasons for soil fertility deterioration include wide gap between nutrient demand and supply, high nutrient turnover in soil-plant system coupled with low and imbalanced fertilizer use, emerging deficiencies of secondary and micronutrients, rise of soil acidity, and nutrient immobilization in red, lateritic and clayey soils. Faulty management of irrigation water stimulates leaching of nutrients and development of waterlogging, salinization and alkalization.

In India, large volume of literature has been generated on physical, chemical and biological properties of soils. However, in most of these researches, the parameters were studied in isolation of elements influencing crop productivity and associated soil properties. Assessment of soil degradation has been made and well-documented in India but linking soil degradation to losses incurred in crop production and deterioration in soil and environmental quality have hardly been addressed. Generation of database for key indicators of soil quality is critical for different soil types, cropping systems, and management practices under various agro-eco-regions of the country for quick assessment of soil health with a view to identify the aggrading/degrading production systems.

Soil Health

Soil health has three components *viz.*, physical, chemical and biological. Status of each is described in this section.

Status of Soil Physical Health

In India, about 90 Mha land is affected by various types of soil physical constraints (Table 1).

These soils (both irrigated and rainfed) produce very low crop yields and have lower fertilizer nutrient use efficiency. Mass flow and diffusion are the two major physical

Table 1. Area and states affected by various soil physical constraints in India

Physical constraints	Area (Mha)	Main states affected
Shallow depth	26.40	Andhra Pradesh, Maharashtra, West Bengal, Kerala and Gujarat
Soil hardening	21.57	Andhra Pradesh, Maharashtra and Bihar
High permeability	13.75	Rajasthan, West Bengal, Gujarat, Punjab and Tamil Nadu
Subsurface hard pan	11.31	Maharashtra, Punjab, Bihar, Rajasthan, West Bengal and Tamil Nadu
Surface crusting	10.25	Haryana, Punjab, West Bengal, Orissa and Gujarat
Temporary water logging	6.24	Madhya Pradesh, Maharashtra, Punjab, Gujarat, Kerala and Orissa

processes by which nutrient ions are transported to the plant root; immobile nutrients are also absorbed through root interception. Management practices which alter water availability and root growth in time and space are likely to influence these physical processes. The major soil physical constraints in Indian soils include low water retention and high transmission, slow permeability, surface and sub-surface mechanical impedance and shallow depth of the soils. These characteristics either restrict crop growth or reduce efficiency of basic inputs, such as water and fertilizer nutrients.

Optimum soil physical conditions are essential to attain maximum input use efficiency and lowering cost of production, which is a big challenge to agricultural scientists. Limited availability and high costs of the three vital inputs in agriculture *viz.*, water, fertilizer and energy demand their rational and sustainable use which is directly related to soil physical health. Soil-water-plant relationships play an important role in determining the use efficiency of these vital inputs. It is, therefore, important that the management practices that moderate and modify these relationships are evaluated and understood in great depth and dimension. It is important to prepare an inventory and mapping of soil-water relations of different agro-climatic situations and soil types, water and nutrient losses and associated changes in physical properties under different land management practices. Models need to be developed for better understanding of soil-water-tillage-nutrient-plant interactions with respect to the use efficiency of water, nutrient and energy and need to be linked with the soil health interventions. Indigenous moisture conservation and nutrient management practices blended with modern scientific knowledge can then be recommended through soil health programmes to achieve higher use efficiency of costly inputs.

Due to agricultural intensification making persistent use of conventional tillage with removal or burning of crop residues, soil health has been constantly and consistently degraded; this has been a matter of serious concern for the scientists, environmentalists and the planners at the global, regional and national levels. Considerable progress has been made in the direction of identifying and quantifying the different soil attributes which can be easily determined in the laboratory/ field and used for evaluating soil health/quality.

As stated above, productive soils have attributes that promote root growth; retain and/ or transmit water for plant growth; promote optimum gas exchange and balance C sequestration and release. All these attributes are, in part, a function of soil physical properties/processes. Some are static, while others are dynamic over a time scale. Some are sensitive to agricultural management practices, others are not. Soil physical indicators proposed by various researchers include soil texture, soil and rooting depth, bulk density, soil porosity and pore size distribution, plant available water content (PAWC), penetration resistance, saturated hydraulic conductivity, soil structure, aggregate size and stability, field infiltrability, organic C, soil surface cover *etc*. Depending on location and situation, these indicators are selectively employed while making assessment of soil health.

Although there are many indicators that regulate current capacity of the soil to function, there are few that can predict whether or not the soil will maintain this capacity following disturbance. The capacity of a soil to continue to support the same potential range of uses in the future that it supports today depends on both its resistance to degradation and resilience. Soil physical processes, such as compaction, crust formation, erosion, and macro-pore formation are difficult and costly to measure. However, the properties on which these processes depend can often be quantified with less money and ease.

Status of Soil Chemical Health

Soil health programmes run by central and state-owned schemes mainly consist of information on soil fertility status and more recently the fertilizer prescriptions based on soil health cards. Besides soil fertility, information on soil reaction (pH) and solute concentration (EC) is also included in soil health programmes.

As per soil test data collected from different soil testing laboratories located in 19 states and compiled by the Indian Institute of Soil Science (IISS), Bhopal, 95, 95 and 48% soils are deficient in available N, P and K, respectively (Table 2). Similarly, All India Coordinated Research Project on Micro- and Secondary Nutrients and Pollutant Elements in Soils and Plants reported that nearly 24.7, 43.4, 14.4, 6.1, 7.9 and 20.6% of the total soil samples analyzed from across the country were deficient in available S, Zn, Fe, Mn, Cu and B, respectively (Table 2).

The IISS, Bhopal have also generated geo-referenced soil fertility maps of 173 districts with support from Department of Agriculture, Cooperation and Farmers' Welfare, Government of India to develop site-specific recommendations across 20 major States (http://www.iiss.nic.in/districtmap.html) for the benefit of the stakeholders. These geo-referenced maps are going to prove useful in monitoring and evaluation of soil fertility as well as in making fertilizer recommendations to ensure balanced fertilization and effective and equitable distribution of fertilizers in the country.

Status of Soil Biological Health

Soil biological health is responsible for life in soil and decides on overall quality of soil including fertility, compaction and nutrient supplying capacity. Soil organic carbon (SOC), an important constituent describing soil fertility/health controls availability of plant nutrients namely: N and S up to 95%; Zn, Cu, Fe and Mn up to 60% and P up to 80%. Accordingly, falling SOC content points to the widening deficiency of N across length and breadth of the country; and accelerated accentuation in the appearance of S, P and micronutrient deficiencies. Abandoning organic manures and extensive tillage favour the breakdown of SOC into CO_2. Resultant decline in SOC encourages poor water holding properties, raises prospects of nutrient leaching and encourages global warming. All these developments are responsible for decline in the potential productivity of a soil.

Limited research has been carried out on the role of soil biota, biofertilizers, phosphate solubilizing microorganisms (PSM), arbuscular mycorrhizae (AM), earthworms, *etc*. on solubilization and enhancement of nutrient supply; developing efficient techniques for inoculation and composting; transformation and turnover of microbial biomass and biomass nutrients and recycling of organic wastes and organic matter dynamics.

Table 2. Extent of nutrient deficiencies in different states/UTs

State/UTs	Extent of nutrient deficiencies (% samples deficient)								
	Nitrogen	Phosphorus	Potassium	Sulphur	Zinc	Iron	Copper	Manganese	Boron
Andhra Pradesh	100	100	58	28.9	22.3	16.8	1.0	1.7	2.8
Assam	100	100	82	16.7	25.6	0.0	3.8	0.0	11.9
Bihar	94	97	96	42.8	37.9	9.9	1.9	7.4	36.3
Chhattisgarh	100	100	59	-	20.1	6.8	3.2	14.1	-
Gujarat	89	100	37	42.0	23.1	23.9	0.4	6.3	17.9
Haryana	100	100	39	35.8	15.3	21.6	5.2	6.1	3.3
Himachal Pradesh	24	88	100	0.0	11.1	0.8	2.1	3.5	32.0
Jharkhand	100	98	79	-	20.3	0.0	0.5	0.0	56.0
Karnataka	81	96	22	-	13.5	3.5	2.7	-	-
Kerala	94	76	82	-	1.2	1.3	11.4	-	24.7
Madhya Pradesh	90	87	46	27.7	66.9	10.2	0.6	1.8	1.7
Maharashtra	100	100	21	26.5	54.0	21.5	0.2	3.8	54.8
Orissa	100	100	69	31.1	22.7	1.8	0.3	1.1	52.5
Punjab	100	47	11	52.3	16.6	6.2	3.6	15.2	17.5
Rajasthan	100	100	24	-	85.5	35.5	63.7	-	-
Tamil Nadu	98	62	32	14.3	65.5	10.6	13.0	7.9	19.9
Telangana	-	-	-	31.8	26.9	17.0	1.4	3.8	16.1
Uttar Pradesh	100	100	61	32.5	33.1	7.6	6.3	6.5	16.2
Uttarakhand	80	100	67	11.2	9.6	1.4	1.4	4.7	7.0
West Bengal	100	90	19	37.4	11.9	0.0	1.2	0.9	46.9
All India	95	95	48	24.7	43.4	14.4	6.1	7.9	20.6

Soil organic matter (SOM) plays a key role in soil fertility sustenance. In soybean-wheat system, organic matter status of soil declined over time in the plots having received imbalanced nutrient inputs on Alfisols of Ranchi. On Vertisols at Jabalpur under soybean-wheat system balanced fertilization with NPK and NPK+FYM improved the SOM status. Thus, assessment of SOC erosion/sequestration under intensive cropping with different management practices holds a key in long-term maintenance of soil quality.

The C sequestration research is gaining credence worldwide in the context of sustainable management of land and soil resources and arresting the deterioration of the environment. The emerging field opens up many new avenues of basic and strategic research relevant to Indian conditions for the next 2-3 decades. The future research should take lead in modelling C sequestration potential of different soils and land use systems and establishing benchmarks and standards for C-trading. With large area under wastelands, the Indian farmers are going to derive potential economic benefits out of the new C-trading venture.

First ever estimate made by Bhattacharya *et al.* (2000) based on 48 soil series taking into account of major soils put the SOC stock of Indian soils at 24.3 Pg [1 Pg = 1 billion tonne (Bt) or 1 giga tonne (Gt) = 10^{15} g]. Latest estimates put the current SOC stock at 63 Pg in the 0-150 cm soil depth. In order to sustain the quality and productivity of soils, knowledge on SOC in terms of its amount and quality is essential. This assumes added relevance in soils of the tropical and sub-tropical parts of the globe, including the Indian sub-continent. In the present scenario, variability in climatic parameters such as the rising temperatures and shrinking annual rainfall in some areas of the country, constitute a potential threat for tropical soils of the Indian sub-continent. Arid climate will continue to remain a problem of crop/agriculture, it promotes soil degradation due to regular depletion of SOC and formation of pedogenic $CaCO_3$, with possible development of sodicity and/or salinity. To combat such a situation from developing, strategic interventions on sustaining health of Indian soils should include restoration of SOC balance, enlargement of the soil C pool by appropriate management techniques (*e.g.*, accelerated agro-forestry plantations). The most unfavourable natural force is the climatic adversity showing up as recurring drought events. In order to deal with the negative impact of drought, extra technical input and resources will be needed to stabilize yields by rainwater conservation and soil health improvement. In pursuance of these goals, it is more necessary now than ever before to undertake intensive research on rehabilitation and sustainable use of the arid soils. If not taken up in a mission mode, deforestation will continue to increase the area under agriculture and obviously this may cause delay in achieving desirable balance between the land and the people. Thus, the soil C stock can act as a single most important parameter in prioritizing areas for the management of the soils in different physiographic regions of the country.

There is a need to characterize the vast amount of biodiversity of fauna and flora present in India. Various challengeable research areas where the microbial community plays a critical role are i) recycling of nutrients in bio-solids and manures, and removal of environmental contaminants, ii) reclamation strategies of degraded soils, iii) improvement in soil physical conditions by enhancing aggregation, and iv) C sequestration. Each of these elements has to be tackled in future through a concerted efforts on: i) characterization and prospecting of large soil biodiversity, ii) characterization of functional communities of soil organisms, and iii) testing of mixed biofertilizer formulations *etc*.

Two basic questions which need to be answered from the point of soil health, in general, and biological soil wealth, in particular are:

1. What is the current status of soil biological properties, which respond to soil health management practices? and
2. What are the easily determinable parameters that can be linked with overall soil health?

The parameters for the first point are many, which researchers employ and routinely determine. Although easy for use by researchers, these parameters can't be adapted by field soil testing procedures/ programmes. Biological indices are reliable as the early warning signals of changes in the soil biological condition. Based on review of global and Indian literature, Rao (2013) concluded that *easy-to-measure* soil biological parameters that give a good idea of soil health include i) organic C and labile C, ii) soil respiration, iii) population of diazotrophs (N fixers), iv) soil dehydrogenase activity, v) soil enzymes *viz.*, β-glucosidase and acid phosphatase, and vi) glomalin content (index of mycorrhiza). All these are inter-related and are of the '*more is better*' type. Based on meta-analysis of 108 datasets of world-wide long-term fertilizer trials at 54 locations, Geisseler and Scow (2014) concluded that the activities of β-glucosidase and acid phosphatase were significantly higher in the fertilized plots. Other specific parameters like microbial biomass and N mineralization potential require more advanced facilities and are excellent for research investigations. Microbial quotient, *i.e.* the ratio of microbial C to organic C (C_{mic}/C_{org} ratio), gives an excellent indication of ecosystem efficiency *i.e*., how efficiently the microflora are able to use the available carbon. Metabolic quotient (qCO_2) or biomass-specific respiration (CO_2-C evolved/C_{mic}) provides an excellent indication of ecosystem equilibrium or maturity.

Since the soil samples used in soil testing laboratories are already air-dried, microbial activity or parameters cannot be determined directly and can only be inferred indirectly. Soil organic carbon (SOC), labile C and soil respiration are the only practicable tests. Determination of the dehydrogenase activity requires expensive biochemicals like 2,3,5 triphenyltetrazolium chloride (TTC), methanol/ethanol for extraction of colour. Because of these limitations use of dehydrogenase activity as everyday soil quality indicator is not recommended.

Land Degradation

According to the latest estimates (NAAS 2010) based on harmonized database, the extent of land degradation in the country is 120.4 Mha comprising of water and wind erosion, and chemical and physical degradation (Table 3). Most of the degraded lands need immediate attention. However, health and quality of the salt-affected and acid soils needs to be restored on priority basis as there are otherwise potentially productive soils. Total salt-affected area in the country is 6.73 Mha; of which 3.70 Mha suffers from sodicity and 2.03 Mha is afflicted with salinity problems. Nearly 25 Mha of cultivated

Table 3. State-wise area affected by various kinds of land degradation in India

Name of State	Area (000 ha) affected by various kind of land degradation							Geogra-phical area (000 ha)
	Water and wind erosion*	Water logged	Alkali/ sodic soils	Acid soils	Saline soils	Mining/ industrial waste	Degraded area	
Andhra Pradesh	8864	36	194	1	60	39	9194	27505
Arunachal Pradesh	380	5	0	1769	0	0	2154	8374
Assam	2366	210	0	1995	0	0	4571	7844
Bihar	1049	133	106	41	40	2	1371	9416
Chhattisgarh	2422	0	13	2342	0	7	4784	13481
Goa	1	6	0	103	0	12	122	370
Gujarat	1012	1	545	0	1559	12	3129	19603
Haryana	303	4	184	2	46	12	551	4421
Himachal Pradesh	984	4	0	76	0	1	1065	5567
Jammu & Kashmir	2001	14	0	78	0	1	2094	22224
Jharkhand	3181	6	0	735	0	21	3943	7972
Karnataka	7799	3	145	93	2	51	8093	19179
Kerala	117	44	0	2426	21	1	2609	3886
Madhya Pradesh	13464	1	124	482	0	24	14095	30864
Maharashtra	8822	27	421	269	171	16	9726	30771
Manipur	150	21	0	1597	0	0	1768	2233
Meghalaya	706	3	0	1023	0	0	1732	2243
Mizoram	0	0	0	1163	0	0	1163	2108
Nagaland	31	3	0	1516	0	0	1550	1658
Odisha	3328	52	0	203	131	8	3722	15571
Punjab	302	034	152	0	0	6	494	5036
Rajasthan	20191	0	152	0	82	0	20425	34224
Sikkim	2	0	0	58	0	0	60	710
Tamil Nadu	2134	39	352	427	11	34	2997	13006
Tripura	74	25	0	709	0	0	808	1049
Uttarakhand	1009	25	0	400	0.	1	1435	5584
Uttar Pradesh	12884	176	1320	0	22	3	14405	23857
West Bengal	1264	43	0	418	408	7	2140	8875
A & N Islands	0	0	0	0	71	0	71	825
Delhi	28	0	0	0	0	0	28	148
Chandigarh	0	0	0	0	105	0	105	11
D & N Haveli	0	0	0	0		0		0.49
Daman & Diu	0	0	0	0		0		0.11
Lakshadweep	0	0	0	0		0		0.03
Pondicherry	0	0	0	0		0		0.48
Total (000 ha)	94868	915	3708	17926	2729	258	120404	328726
Total (M ha)	94.87	0.91	3.70	17.93	2.73	0.26	120.40	328.73

*Includes area affected by wind erosion of 11560 thousand ha (Gujarat-1 thousand ha & Rajasthan-11559 thousand ha).

Source: NAAS (2010)

lands with pH less than 5.5 are critically degraded (Sharma and Sarkar 2005). The productivity of these soils is very low (< 1 t ha^{-1}) due to deficiencies of P, Ca, Mg, Mo and B, and toxicities of Al and Fe. Since the deficiencies of micro- and secondary nutrients are progressively emerging as the yield-limiting factors in acid soils, in addition to the soil acidity-related constraints, soil tests need to be calibrated for recommending fertilizer dose for a whole cropping sequence based on initial soil test values for these soils.

Soil health *vis-à-vis* Human and Animal health

A healthy soil produces a healthy plant by supplying all the essentials nutrients in right amounts and proportions. Humans and animals eating such plants are presumably healthier. Health, however, is not a static but a dynamic process. Just like any nutrient cycle, the land on which soil, plant, animals and human beings exist can be compared to an electric circuit where soil-plant-animal-human beings are components of the circuit. Food chains are the living channels. These conduct energy forward on death and decay of plants and animals return it to the soil, which in turn, get worked up with solar energy, microbes and mineral matter to produce humus. Consequently, there is a relationship between humus and human health. But neither soil scientists nor medical professionals have paid due attention to the relationship between soil and human health. To some extent this important issue was touched upon by geo-chemists and only in exceptional cases by medical scientists. In *Ayurveda,* a discipline called "*Dravyagunashasthra* and *deshavichara*" links the medicinal properties of the herbs to the soil, location and region where these are produced. Interestingly, Veterinary Science has been far more aware of this kind of relationship and an extensive literature exists on the problem of deficiency and excess of mineral elements in animal nutrition.

At least 50 nutrients are needed in the human diet to sustain life, which include water, carbohydrates, proteins, fats, minerals (macro- and microelements), and vitamins. Vitamins and microelements are termed as essential micronutrients for human nutrition. Of the 50 nutritional components that are required to meet the metabolic needs of humans, only water, K, P, S, Ca, Mg, B, Cl, Cu, Fe, Mn, Mo and Ni are considered essential to all plants. Cobalt (Co) is essential for N-fixation in legumes and is an essential component of the essential vitamin cobalamin. Deficiency of cobalamin (*i.e*., pernicious anaemia or vitamin B_{12} deficiency anaemia) in humans is a significant problem in certain regions of the world including Indian subcontinent, Mexico, Central and South America and among vegetarians all over Asia. A thesis that there exists a link between soils and human health has been recognized for thousands of years; however, the scientific study of how soils influence human health is a recent endeavour (Katyal *et al.* 2004; Singh 2009; Shukla *et al.* 2014; Brevik and Sauer 2015).

Micronutrient malnutrition is a major public health problem for the poor people of the developing nations. As estimated, around 40% of the world's population is facing such problem. During the last four decades, the number of people affected by trace elements malnutrition has shown noticeable increase. This coincided with the happening of Green Revolution followed by widening of area suffering from deficiency of one or the other essential micronutrient.

As compared to human beings, livestock is more susceptible to deficiency of trace elements in the plant and water they consume. Soil composition dictates the nutrient content of the food, feed and fodder. The extent of problem associated with trace element deficiencies varies greatly from area to area depending on geological minerals, soil type, vegetation, climatic conditions, farming practices, quality and quantity of manures, and fertilizers and water use practices. After knowing the deficiency of a specific nutrient, desired minerals are supplemented with the feeds. As far as the food of the human beings is concerned, most of the time, it is derived from diverse sources and from different places representing diverse soil-crop-climatic conditions. Thus, it has only been possible to demonstrate association between the occurrence of certain diseases in humans *vis-a-vis* concentration of certain trace elements in the soil.

Soil is a crucial component of rural and urban environments, and in both places land management is critical to the soil quality maintenance. Due to increased anthropogenic activities, soil acts as the sink for several pollutants like pesticides, herbicides, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, heavy metals and many inorganic salts. These pollutants have adverse impacts on soil physicochemical environment, nutrient cycling/transformation processes, soil biodiversity, plant growth, food quality through contamination, *etc*. Large quantities of urban wastes produced in different cities cause water, air and soil pollution. Mining, manufacturing and the use of synthetic products (*e.g.* pesticides, paints, batteries, industrial wastes, and land application of city and industrial sludge) contaminate the urban and agricultural soils with carcinogenic heavy metals. Excessive heavy metal accumulation in soils leads to introduction of toxic elements in the food chain and once in food chain these pose a serious threat to animal and human health. Wide-spread occurrence of geo-medical problems of anaemia, goitre, dental caries, and coronary artery diseases is directly related to the reduced Fe, I, F and Mg contents in the food, respectively. Selenosis in animals and fluorosis in human beings are caused due to toxic levels of Se and F in food and drinking water, respectively.

Of late, high fertilizer-N-use linked pollution of groundwater with nitrates has become a serious health concern in areas inhabiting coarse-textured excessively-irrigated soils receiving higher doses of fertilizer N. Nitrate pollution of ground water above the permissible levels (11.3 mg NO_3^--N L^{-1} of water as safe limit in drinking waters) in intensive cultivated areas of Punjab, Haryana, Gujarat, Maharashtra and Andhra Pradesh has been reported.

Nitrous oxide (N_2O), a potent greenhouse gas, has the global warming potential of 298 relative to 1 of CO_2 over a 100-year period. Fertilizer N is the largest source contributing around 77% of the total direct N_2O emissions from the agricultural soils. Most efficient management practices to reduce N_2O emission are site-specific integrated nutrient management, use of nitrification inhibitors, supplementation of nitrogenous fertilizers by biofertilizers, organic manures, demand-driven N application using leaf colour chart (LCC), intercropping with legumes and use of deep-placed urea supergranules (USG).

Assessment of Research and Development Initiatives

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 kg C ha^{-1} 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. The year-wise numbers of STLs sanctioned under the scheme are given in table 4.

Table 4. Year-wise numbers of soil testing laboratories (STLs) sanctioned in the country

Component/year	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	Total
New static STLs	42	66	16	0	0	10	5	139
New mobile STLs	44	62	10	2	0	5	9	132
Strengthening of the existing STLs	39	107	9	15	1	2	-	173
Total	125	235	35	17	1	17	14	444

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 (NWDPRA), 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 stand-alone 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 ($N:P_2O_5:K_2O$) 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 (N_2), 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 over-flowing 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, un-healthy 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 (<1 t ha^{-1}) 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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Soil Health Measurement Techniques

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Soil is a wonderful gift of nature to humankind. It performs many functions. Some are ecological *viz*., i) biomass production; ii) filtering, buffering and transforming actions; and iii) providing a biological habitat and gene reserve; and others are linked to non-agricultural purposes *viz*., i) as a physical medium; ii) as a source of raw materials; and iii) as a cultural heritage - palaeontological and archaeological treasures. Its well-being is, thus, essential for the very existence of mankind. However, because of natural as well as anthropogenic reasons there is widespread degradation of soils. In India, out of the total cultivated land area of 142 million hectares (Mha), about 105 Mha suffers from different forms of degradation. The extent and severity of such degradation, however, varies (Bhattacharya *et al*. 2015). Maintenance of soil health and/or curbing its degradation is of paramount importance. If its health is maintained, a large number of global challenges *viz*., food security, water security, waste recycling, protection of biodiversity, abatement of climate change *etc*. can also be met. In fact, maintenance of its health is ultimately linked with the health of plants, animals and also humans.

Domestication of soils by human disturbances for intensive farming hampered a large number of important soil processes. These are reflected through three major events *viz*., a higher loss of soil than its production, a greater loss or release of nutrients than its addition and a higher loss of carbon than its replenishments (Amundson *et al*. 2015). On an average, it is estimated that globally about 75 billion tonnes of productive soil with a monetary value of US$ 400 billion per year is lost along with 8.4 billion tonnes of nutrients and 1190 Tg (Teragram, 1Tg= 10^{12}g) of carbon because of such disturbances and domestication. All these adverse developments make the soil sick. The sickness is also reflected in declining partial factor productivity of fertilizers, increasing greenhouse gases and pollution load, widespread deficiency of nutrients and declining quality of crops grown onto it. Assessment of soil health is, thus, important for undertaking necessary rehabilitation measures. But the major constraint for undertaking such measures is that most of the soils are under private ownership; adoption of technology for up-keeping the health through assessment depends on the judgment of its owners not on state. Any effort towards the rehabilitation measures will be successful only on active participation and satisfaction of the land/soil owners. Sincere efforts should be made for upkeeping its health following proper assessment.

Measuring Soil Health

Soil health is measured mainly for two purposes: i) monitoring for making an inventory as to its status (health); and ii) assessing the impacts of human perturbations onto it. Truly, such assessment should be done against undisturbed pristine sites. But, it is very difficult to find such sites (as reference level) for comparison for a possible degradation or aggradation caused by human disturbances. Under such situations, we can make at least a relative assessment of health of soils with varying anthropogenic stresses for screening and subsequent adoption of less/non-damaging types for upkeeping the health. Accordingly, a sequential framework for assessment of soil health is given hereunder (Table 1) wherein a number of interrogations are made as to the purpose, functions, processes that support the functions, critical soil properties/indicators with their threshold levels, surrogate indicators and adoption of standard methods for a logical interpretation of the whole process. Such assessment of soil health should be done keeping in mind the management goals with associated soil functions and screening of relevant indicators. An example is given below (Table 2) linking some relevant indicators along with the functions

Table 1. A sequential framework to assessing soil health

Steps	Sequential framework	Question implied by the framework
1	Purpose	What will the soil be used for?
2	Functions	What specific role is being asked of the soil?
3	Processes	What key soil processes support each function?
4	Properties/attributes	What are the critical soil properties and their critical or threshold levels?
5	Indicators, surrogates, or pedotransfer function	When the attribute is difficult to measure or not available, which indirect or related property or properties can be used in its place?
6	Methodology standardization	What methods are available to measure the attribute? Technical rules and protocols for soil sampling, handling, storage, analysis and interpretation of data.

Table 2. A few indicative management goals with associated soil functions used to screen soil health indicators

Ecosystem goal	Soil function	Indicators
Food-feed-energy security	Nutrient cycling including SOC	Microbial biomass C, potentially mineralizable N, dehydrogenase activity, soil respiration, available N, P, K, micronutrients, cation exchange capacity, β-glucosidase
Water security	Water relation	Hydraulic conductivity, maximum water holding capacity, porosity, SOC
Waste recycling	Physical, chemical, biological and cultural environment	Soil aggregate stability, bulk density, sesquioxides, microbial diversity, SOC
Biodiversity protection	Filtering and buffering	Bulk density, hydraulic conductivity, SOC, cation exchange capacity
Environmental protection and climate change abatement	Resistance and resilience	SOC, bulk density, potentially mineralizable N, dehydrogenase activity

for delivering the major ecosystem services of soils. This is the foundation of the assessment and needs to be done with utmost care and intelligence.

Selection of Indicators

Selection of an indicator constitutes an important part of soil health measurement. It is of two types– one, inherent indicators - these are native and quasi-permanent in nature, undergo little changes; and the other, dynamic indicators – these reflect/capture the signatures of perturbations soils are subjected with. They are selected based on a number of principles, as indicated below:

i) A suite of indicators, both inherent and dynamic types required to capture changes in soil health because of its complexity
ii) Come through a logical sieve, not a straightjacket approach
iii) Cross-functional/all-encompassing (aggregative/black-box) type
iv) Early warning type
v) Surrogacy - not apparent for lacking database
vi) Meeting peculiar needs
vii) Climate change indicators
viii) Farmers' friendly

These are to be chosen through logical sieving, not following a straightjacket approach and should be all-encompassing ones that set early alarms, are farmer-friendly, and ably meet peculiar needs of assessment. For example, to assess the effects of different management practices employed in long-term experiments, we have to choose such indicators that undergo little changes during the archive periods sometimes for decades together to capture accurately the trend of the actual changes occurring in soil because of adoption of a specific management practice, say balanced and imbalanced fertilization or with and without farmyard manure (FYM) application *etc*. The indicators should encompass ecosystem processes, and be sensitive to variations in management practices, a component of existing soil database and inexpensive with high throughput too for routine use. However, the problem with selection of indicators is that it is like *the more, the merrier*; but every analysis is costly. So, the number of indicators must be reasonable in number, but all-encompassing such as physical, chemical and biological in nature (Figure 1).

Biological Indicators and Soil Resilience

As mentioned earlier, assessment of soil health is done for undertaking rehabilitation measures, if there is any degradation. To make an effective rehabilitation, knowledge about the recuperative/resilient capacity - the ability to bounce back to original conditions after a disturbance of soil is needed. Good protocol for measuring the resilience capacity of soil is, however, not available; although many researchers have made modest attempts to develop such a protocol (Seybold *et al.* 1999; Mandal 2013; Basak *et al*. 2014). Such (resilience) capacity in soil is known to be imparted mainly by its biological activities/

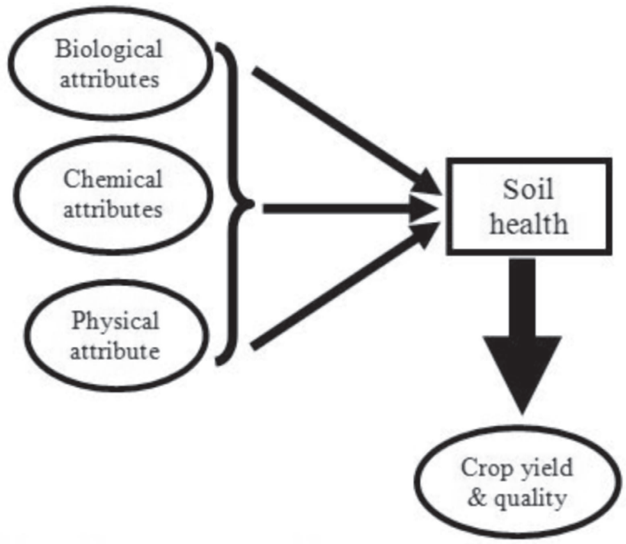

Figure 1. Schematic diagram for integration of indicators

properties. Accordingly, inclusion of a few biological indicators is essential in the protocol for an effective assessment of soil health. On these, estimation of respiration, microbial biomass carbon, multi-enzyme profiling and on-site visual recording of soil flora and fauna are emphasized. In addition, soil microbial taxa and community structure using PLFAs (phospholipid fatty acids), T-RFLP (terminal fragment length polymorphism) *etc*. have also been advocated recently for soil health assessment. However, in general, methods for measurement of biological properties are cumbersome, time-consuming and costly. But to include in routine analysis for assessment of soil health, methods of estimation of different indicators must be simple, inexpensive and with high throughput, as indicated earlier. In such situations, important indicators having tortuous methods may be estimated out of their surrogates with validated and robust pedotransfer functions under different conditions. Surrogate or pedotransfer functions for a few physical and chemical indicators are available in global literatures, but such functions for biological indicators are hardly available or validated for use for different agro-ecosystems. If possible, methods having the following desirable features listed in table 3 may be picked up for inclusion in the assessment of soil health for making it cost effective and user-friendly.

Alternative Indicators

Now-a-days, attempts are being made to find alternative to costly laboratory analysis-based indicators with those having methods involving visual, morphological and VIS-NIR spectroscopic approaches costing very little per sample with high throughput and easy to use.

Visual and morphological estimation of earthworm number, organic matter colour, sub-surface compaction, erosion, crop conditions *etc.* that can be done easily may constitute an important dataset for assessment of soil health. In fact, such assessment should

Table 3. A few desirable features of methods for measuring indicators

a) High throughput	a) Ease of use
b) Storage	b) Potential reference material
c) Archievability	c) Deployment status
d) Sample collection	d) International comparisons
e) How much soil	e) Indian infrastructure
f) Cost – Hardware/labour	f) Multi-parametric in nature

include a few indicators originating from the farmers' perception of soil health so that they themselves, without doing rigorous estimation in laboratory could judge, the actual state of their soils. However, standardization of methods for these with simple tools is required for adoption. Further, introduction of some sorts of mechanization in analysis of different indicators is essential for covering so many farm holdings under different soil types and production system in India. Introduction of the use of VIS-NIR or X-ray fluorescence spectroscopy (O'Rourke *et al.* 2016) is thus a welcome addition along with remotely sensed datasets generated through satellites and validated with ground-truthing in spite of having some inherent shortcomings *viz.*, weak spectral signals, spectral overlapping, noise, complexity in interpretations, *etc*. associated with such rapid and mass scale measurements. Again, GIS-based models (GEMS, Roth C, CENTURY, *etc*.) are also advocated for effective monitoring of the status of soil of the country.

Formulation of Minimum Datasets

Once the indicators are chosen and database generated for each of them for soils subjected to different management practices, a critical statement need to be made as to the aggrading or degrading influence of the practices onto their (soils) health. On the basis of the value of individual indicators, sometimes it is difficult to assess the health of soil unless the databases are judged for their influence on the goal functions of soil. Accordingly, the databases are screened through a number of parametric and nonparametric statistical tests based on their influence on goal variable to formulate a minimum dataset (MDS) of indicators. Subsequently, the database for different indicators so screened are validated with goal variables or with functions we are expecting from the soils through a few statistical tools *viz*., simple correlation, multiple regression, principle component analysis (PCA), discriminate analysis, *etc.* to indicate their (indicators) representation in the variability of goal functions. The whole process of formulation of MDS has elegantly been described by Andrews and Carroll (2001) and Andrews *et al*. (2004) (Figure 2). Subsequently, many researchers in India have screened out master indicators for different soil types and cropping systems for assessment of soil health as a function of biological productivity/sustainable yield only (Table 4); although a few of them have assessed soil quality using two management goals *viz*., i) productivity and ii) environmental protection, and also identified two distinguishing minimum datasets of indicators for those goals (Bhaduri *et al.* 2014; Bhaduri and Purakayastha 2014). It is, however, observed that the indicators varied significantly even within a soil type or production system. For example, variation in screened master indicators for rice-based cropping systems across the globe is apparent from the table 5. All these results indicate that there occurs little communality

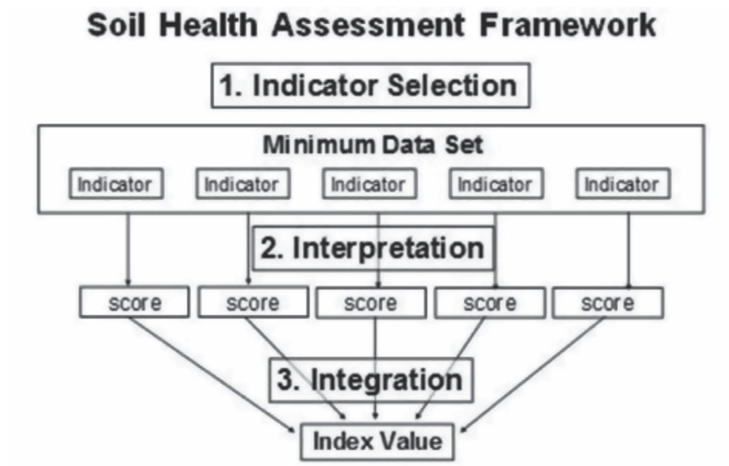

Figure 2. Schematic diagram showing all the processes *viz*., indicator selection, minimum dataset formation, interpretation and integration involved for calculation of soil health index

Table 4. Some indicators identified for different soil types and cropping systems

Centre	Soil type	Cropping system	Indicators identified
AAU	Clay loam	Rice- rice	Available K, Zn, OC, %BS and dehydrogenase activity
ANGRAU	Sandy loam	Groundnut-redgram	MBC, pH, available P and K, WHC and Zn
BHU	Sandy loam	Rice-lentil	OC, available P, Ca and Mg
CRIDA	Sandy	Sorghum-castor	HC, available N, P, K and S, and MBC
CRIJAF	Sandy loam	Jute-rice-wheat	Available P and K, MBC, MWD and OC
CRRI	Sandy clay loam	Rice-rice	Dehydrogenase activity, available K and OC
OUAT	Silty clay loam	Rice-field pea	MBC, OC, available S and P
BCKV	Sandy loam	Rice-wheat	MBC, OC, mineralizable N and alkaline phosphatase activity
IARI	Loam	Maize-wheat	Available N, OC, MBC, alkaline phosphatase activity, BD and available Zn
CRIDA	Sandy loam	Sorghum-mung bean	Available N, Available Zn, available Cu, MBC, MWD and HC

Source: Mandal *et al*. (2005); Masto *et al*. (2007); Sharma *et al*. (2008)

among the screened indicators even for similar production system raised at different geographical sites. One of the major tasks for researchers is to work on finding commonality in indicators for different soil types, production systems, *etc*. so that easy and inexpensive methods are developed for those common master indicators for their inclusion in routine analysis in soil testing laboratory for assessment of soil health. Again, studies assessing health of soils to meet other ecosystem services has hardly been done in India, although its role and capability for providing water security (NO_3 pollution), waste recycling, biodiversity and environmental protection and climate change abatement are in urgent demand for assessment. A modest beginning can be made with the existing long-

Table 5. Some soil health indicators identified for rice-soils in different countries using different statistical methods

Cropping system	Country	Methods used	% of the total variability explained	Identified soil quality indicators
Lowland rice (Lima *et al*. 2008)	Brazil	PCA/DA	78% with 29 indicators; ~ 99% with DA using PCA identified data set	BD, SOC, earthworms, available Zn, Mn and MWD
Hilly red soil with rice (Li *et al*. 2013)	China	PCA	78% of data set from 17 attributes (PCA)	SOC, available N, P, K and sand
Rice-rapeseed in coastal reclamation area (Li *et al*. 2013)	China	PCA/DA	78% with 22 indicators; ~ 99% with DA using PCA identified data set	SOC, dissolve SOC, soil water table; and irrigation water Cl^-, Na^+ and EC of water
Inceptisols with rice-wheat-jute (Chaudhury *et al*. 2005)	India	PCA	95% with 10 indicators	DHA, available P, MWD and total N
Inceptisols with rice-wheat (Bhaduri and Purakayastha 2014)	India	PCA/ Conceptual framework (Expert opinion)	72% with 17 indicators 69% with 17 indicators	Fe, HC, Zn, MWHC, WSA, PMN and MBC (Rice) Cu, WSA, available P, PMN, respiration, Mn, DHA and SOC (Wheat)
Inceptisols with rice-potato-sesame (Basak *et al*. 2016a)	India	PCA/DA	87% with 27 indicators; ~ 91% with DA using PCA identified data set	DHA, available K, CEC and pH_{Ca}
Entisols with rice-potato-sesame (Basak *et al*. 2016a)	India	PCA/DA	85% with 27 indicators; ~ 92% with DA using PCA identified data set	SOC, pH_{Ca}, BD, mineralizable-N and β-glucosidase
Alfisols with rice-potato-sesame (Basak *et al*. 2016a)	India	PCA/DA	83% with 27 indicators; ~ 99% with DA using PCA identified data set	DHA, very labile C, mineralizable-N and MBC

term experiments where along with biological productivity, biological diversity, carbon budgeting, crop quality, *etc.* may be included as goal variables.

Calculation of Soil Health Index

As mentioned earlier, it is difficult to draw inference from the values of each of the screened indicators for a production base as to its aggregation or degradation because of multidimensional trends (positive, negative, or no change) and intensity (degree) of changes occurring in the indicators. To solve the problem, indicators are married together (Figure 2) into a combinable index (soil health index) for getting a unique value for describing if there is any aggradation or degradation in soils owing to a specific management practice.

Table 6. Effects of balanced and imbalanced fertilization and use of FYM on soil health index (SHI) across soil types and cropping systems

Treatment/ centre	AAU	ANGRAU	BHU	CRIDA	CRIJAF	CRRI	OUAT	BCKV
Control	2.27	0.92	1.63	0.95	1.04	2.77	0.31	2.78
N	2.60	-	1.48	-	1.38	2.91	0.35	-
NP	2.59	-	-	1.02	1.66	3.21	0.78	-
NPK	2.79	0.97	1.52	-	1.87	3.10	0.81	2.69
NPK+FYM	2.84	2.00	1.87	1.27	2.10	4.00	1.13	3.63

Source: Mandal *et al*. (2005)

To combine the indicators, sometimes different weightages are given to them based on personal judgement or values of the coefficients of determinations of multiple regression, principle component analysis (PCA), discriminate analysis (DA), *etc*. associated with those indicators during screening through different statistical methods in the form of weighted additive, simple additive, *etc*. (Andrews and Carroll 2001; Lima *et al.* 2008).

The soil health index (SHI) is worked out for soils under different treatments and cropping systems in a large number of long-term fertility experiments in India by different researchers (Mandal *et al*. 2005; Chaudhury *et al*. 2005; Sharma *et al*. 2005, 2008; Mohanty *et al*. 2007; Masto *et al*. 2007, 2008; Bhaduri and Purakayastha 2014; Bhaduri *et al*. 2014; Kundu 2014; Basak *et al*. 2016a,b,c). Most of them found higher SHI values in soils cultivated with balanced use of NPK than those cultivated with the imbalanced ones (Table 6). Again, values of such SHI were always higher with than without organics/FYM (Tables 6 and 7). Recently, while assessing SHI for soils in farmers' fields, Basak (2011)

Table 7. Effects of organics on soil health index for Inceptisols, Entisols and Alfisols under farmers' field

Soil orders	Cropping systems	NPK		NPK+FYM	
		Range	Mean	Range	Mean
Inceptisols	Rice-potato-seasame	0.35-0.77	0.49	0.35-0.70	0.63
Entisols	Rice-potato-seasame	0.36-0.50	0.41	0.34-0.55	0.46
Alfisols	Rice-potato-seasame	0.32-0.82	0.53	0.41-0.81	0.64
Alfisols	Rice-wheat	0.33-0.66	0.43	0.40-0.44	0.49

Long-term experiment

Treatments/ Cropping systems	R-M-S (Basak *et al.* 2011)	Treatments/ Cropping systems	R-W (Basak *et al.* 2016c)
Fallow	0.78	Fallow	0.71
Control	0.64	Control	0.64
NPK	0.73	NPK	0.70
NPK+ FYM	0.89	NPK+FYM	0.91
NPK+GM	0.80	NPK+PS	0.86
NPK+GM+*Azotobacter chroococcum* +*Seudomonas putida*	0.83	NPK+GM	0.85

Source: Basak *et al.* (2016b)

as well as Biswas (2011) identified not only the master indicators for SHI but also determined their critical values (Table 8) for maintaining a higher yield and a good soil health in rice-growing Inceptisols, Entisols and Alfisols of West Bengal. Ingeniously, they could also determine the critical values of SHI for those soils for getting a good crop yield (Table 8). Similar critical values, both optimum and threshold, of indicators for different soils and production systems need to be worked out across the country. Once it is done, the ultimate aim of screening the master indicators and estimation of the optimum and threshold values for such indicators for inclusion in the routine analysis of soil testing laboratory for assessment of soil health will be fulfilled. To ensure this, as indicated earlier, there must be an easy method of determination with a high throughput for all those screened indicators, and as such, efforts may be given to develop such methods for the important indicators.

A Priority

A comprehensive assessment of health of any living or non-living entity is a tortuous proposition. Soil is no exception, in spite of having a reasonable scientific protocol for estimation of its health, there is no taker to measure soil health because of some short-comings like (a) poor standardization of some methodologies, (b) some methods are out of reach in most parts of India, (c) spatial scale problems (huge soil heterogeneity), (d) poor definition of soil natural conditions (climate and vegetation), and (e) poor definition of soil function to be tested for soil health. As such, till now there is hardly any success in popularizing the concept. As such, no comprehensive action exists for assessment of all the elements describing soil health across the country. Some piecemeal efforts have been made here and there towards such assessment using a few long-term experiments, in particular. An initiative may thus be taken, on priority, for a holistic assessment of soil for most of its ecosystem functions with all relevant indicators at least for all the 291 benchmark soils along with the existing long-term experiments. These ongoing investigations may be utilized to create a baseline for future and identify the key factors causing degradation of soil health.

Enlarging the Mandate of Soil Testing Laboratory

Soil is the foundation of food, water, energy and health security to humankind. Because of its importance for our survival, need is to take proper care of its health. The existing mandate of the soil testing laboratories may be too limited and narrow to accommodate the above requirements and needs to be enlarged. It should encompass not only the testing of soil and making fertilizer recommendations, but also act as the custodian of soil health in the area of its jurisdiction. Further, it should monitor and check soil/ land degradation and police over the abuses and misuses of soils, if required with statutory authority. This is essential not only for saving this non-renewable resource, but also for fulfilling the innate message of the National Soil Health Mission launched recently by the Government of India (GOI).

National Initiative and Outreach Activities

The GOI has taken a big initiative to issue soil health card for each of the 140 million farm holdings of the country within a span of two years' time. If it is done properly and

Table 8. Critical values of key indicator and soil health index for rice-growing Inceptisols, Entisols and Alfisols with rice-potato-sesame and rice-wheat cropping systems

Cropping systems	Soil orders	Key indicators identified	Optimum value	Threshold value
Rice-potato-sesame	Inceptisols	CEC [cmol(p^+)kg^{-1}]	14.9	7.9
		MBC (µg C g^{-1})	625.6	214.7
		Dehydrogenase (µg TPF g^{-1} soil $24h^{-1}$)	104.7	34.9
		Available Zn (mg kg^{-1})	2.3	0.4
	Entisols	Organic C (g kg^{-1})	7.6	5.3
		Aggregate stability (%)	34.5	19.0
		Saturated hydraulic conductivity (cm h^{-1})	0.25	0.34
		Dehydrogenaseactivity (µg TPF g^{-1} soil $24h^{-1}$)	54.1	27.5
	Alfisols	Organic C (g kg^{-1})	5.8	3.1
		Aggregate ratio	0.35	0.15
		Arylsulphatase activity (µg p-nitrophenol g^{-1} soil h^{-1})	39.4	18.9
		Available Zn (mg kg^{-1})	1.27	0.54
		β-glucosidase (µg p-nitrophenol g^{-1} soil h^{-1})	42.5	17.8
Rice-wheat	Alfisols	Very labile C (g kg^{-1})	3.5	1.8
		Mineralizable C (µg C g^{-1})	286.0	178.9
		Mineralizable N (µg NH_4^+ g^{-1})	34.9	15.4
		β-glucosidase activity (µg p-nitrophenol g^{-1} soil h^{-1})	58.5	22.4
Rice-rice	Inceptisols	Available Zn (mg kg^{-1})	1.68	0.98
		Bulk density (Mg m^{-3})	1.22	1.50
		β-glucosidase activity (µg p-nitrophenol g^{-1} soil h^{-1})	68.5	32.1
		Urease (µg NH_4N g^{-1} soil $2h^{-1}$)	63.5	27.2
	Entisols	Dehydrogenase activity (µgTPF g^{-1} soil $24h^{-1}$)	91.5	25.4
		Aggregate stability (%)	64.8	17.5
		Total organic C (g kg^{-1})	11.6	10.7
		pHw	5.7	5.3
	Alfisols	Oxidisable organic C (g kg^{-1})	7.8	5.7
		β-glucosidase activity (µg p-nitrophenol g^{-1} soil h^{-1})	51.2	23.8
		Aggregate stability (%)	52.2	27.3
		Mineralizable C (µg C g^{-1} soil)	273.4	198.1

Soil health index

Cropping systems	Soil orders	Optimum value	Threshold value
Rice-potato-sesame	Inceptisols	0.58	0.33
Rice-potato-sesame	Entisols	0.47	0.31
Rice-potato-sesame	Alfisols	0.62	0.31
Rice-wheat	Alfisols	0.52	0.31

Source: Basak (2011); Biswas (2011)

farmers are sensitized and if so required, given incentives for adoption of the recommendations in the cards particularly for fertilizer application in their fields, use efficiency of costly and heavily subsidized fertilizers will be increased significantly. And as such, it is a great opportunity for the soil scientists/agronomists of the country to serve for the national cause. Everyone should come forward to help in whatever way he or she can for successful implementation of the programme. However, considering the presently available infrastructure facilities and the technical quality of the manpower not only for analysis and sampling, but also for making recommendations on fertilizer use decisions is a herculean task. In such a situation, an alternate option is that the soil-led strategy may be complimented with a plant-led strategy for fertilizing crops based on typical deficiency symptoms, comparing with leaf-colour charts and also remotely sensed spectral reflectance with accurate inferences validated by ground-truthing. All these complementary avenues may add huge strength in assessing the state of soil health throughout the country. In many cases, it is observed that farmers are reluctant to get their soils analyzed and use fertilizer as per the analytical reports and recommendations made, even if they get a free service. There are several reasons for this; one of the most common is delayed receipt of the soil test report. Shortening the gestation period is one of priorities for attracting farmers towards Soil Health Card Scheme. Again, the present soil health card sometimes also proves to be not user friendly and wholesome. Such cards must be of an easily understandable type so that even illiterate farmers can assess the health of their fields/soils from the reports whether a net aggradation or degradation occurs due to adoption of a specific management practice or not. A simple and easily understandable card is presented below (Figure 3). From the report of the card, status of a soil can easily be assessed by even the farmers through the progress of inner circle towards the outer circle indicating a betterment of soil health.

The importance of soil health and application of fertilizer based on soil test report needs no emphasis. Accordingly, farmers are to be sensitized for the issue through elaborate outreach activities using mass media and other avenues, such as creation of soil FM radio, documentaries of success stories regarding upkeeping soil health following soil test based fertilizer application and their telecast over National TV channels, engagement of soil science/agronomy fellowships to empower farmers deliberating in science club, farmers club, NGOs and celebration of a National Soil Health Day, *etc.* These are the priorities and should be launched immediately for effective execution of the National Soil Health Mission for upkeeping soil health for posterity.

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Soil Health Mission: Government Initiatives

Ashok Dalwai and Vandana Dwivedi

Soil is the primary medium of crop cultivation. It provides the plant, the basic anchor, letting it spread its root system to draw the needed nutrients and transfer them to above-ground growth for physiological conversion into vegetative and grain/fruit/flower forms. One often hears on the importance of soil conservation. It is no gain just saying that since conservation of this natural resource is critical for food and environmental security. After all, it takes Mother Nature one thousand years to produce one inch layer of soil, which can be lost in no time through erosion, if proper soil conservation practices are not in place. However, it is equally important to appreciate that the conserved soil can be useful, only when it retains its texture and structure in a manner that is conducive for healthy crop growth and yield.

Soil health is linked to the status of various nutrients (fertility), useful biota and physical parameters. Hence, the need for nurturing the soil health for sustaining agriculture as a giver of food and supporter of multiple enterprises is that it cater to man's varied requirements and continues to perform its environmental regulatory functions.

The technology-driven farming started in mid 1960s with the advent of Green Revolution (GR), which engendered significant changes in food production and livelihood security of farmers, traders and other stakeholders. Green Revolution was principally based on high responsiveness of plant varieties to intensive use of agro-chemicals and water. However, indiscriminate use or abuse of GR technologies led to several problems, often termed as second generation problems, challenging the sustainability of production and productivity gains achieved earlier. Soil health deterioration is considered as one of the major second generation problems. Depletion in soil organic carbon levels, emergence and spread of micronutrient deficiencies, and sub-soil compaction have been frequently documented. Inadequate and imbalanced use of plant nutrients lead to excessive mining of finite nutrient reserves in the soil rendering the latter progressively poorer over the years. Such nutrient mining has serious implications, namely, (i) more acute and widespread nutrient deficiencies; (ii) declining fertilizer use efficiency and returns from money spent on these and falling response ratio of other inputs; (iii) a weakened foundation for high yielding sustainable farming; and (iv) escalating remedial costs for rebuilding depleted soils.

On-station and on-farm studies carried out by Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs) have clearly shown that soil health could be restored and improved through soil test–based balanced and integrated use of plant nutrients. Similarly, problems like salinity, sodicity and acidity could be effectively addressed with the adoption of appropriate technologies. Farmers' awareness regarding soil health restoration technologies has to be increased through various schemes and programs, so as to prevent further deterioration of this invaluable natural resource. Government of India, through its five year plans, as also several State Governments have responded positively through various soil health management initiatives over the years, though they may not have been comprehensive in nature.

Past Initiatives

Appropriate governmental support and policies are a pre-requisite, not only for technology generation but also for technology dissemination and capacity building through human resource development and creation/strengthening of infrastructure. Soil health management has always been one of the top priorities of the Department of Agriculture and Cooperation (DAC) (now renamed as Department of Agriculture, Cooperation and Farmers' Welfare - DAC&FW) in the Ministry of Agriculture (now renamed as Ministry of Agriculture and Farmers' Welfare – MoA&FW). Hence, Government of India has initiated several central sector schemes during different Five Year Plans to sustain high productivity and enhance farmers' income through soil health improvement and judicious use of plant nutrients and soil ameliorants. In order to promote balanced use of fertilizers, a centrally sponsored scheme entitled 'Balanced and Integrated Use of Fertilizers' was launched by the DAC in the year 1991-92. During X Five Year Plan, this scheme was subsumed in the 'Macro Management Scheme', which included distribution of Soil Health Cards (SHCs) to the farmers by State Departments of Agriculture.

'National Project on Development and Use of Biofertilizer' started in 1980s was another important milestone that strengthened biofertilizer production and marketing infrastructure, and improved farmers' awareness on the use of this low-cost and eco-friendly ingredient of integrated plant nutrient supply. This national project with headquarters at Ghaziabad and six regional centers in different parts of the country (Hisar, Jabalpur, Nagpur, Bengaluru, Bhubaneswar and Imphal) was later transformed into 'National Project on Organic Farming' (NPOF) during XI Five Year Plan. Visible increase in the production of biofertilizers, which rose from merely 100 tonnees at the initial stage of the project to more than 51,870.67 tonnes by 2013-14, is a manifestation of the success of this project.

Soil health management received a focused attention during XI Five Year Plan, when a dedicated project 'National Project on Management of Soil Health and Fertility' (NPMSH&F) was launched by the Department. The major components of NPMSH&F were (i) strengthening of soil testing laboratories; (ii) promotion of integrated nutrient management; (iii) promotion of micronutrients in rice and wheat; (iv) application of lime to acid soils; (v) application of gypsum to sodic soils; and (vi) integrated nutrient management in pulses. State-wise funds released under this Scheme are given in Table 1 (Dwivedi 2012).

Besides NPMSH&F, a few components of other two national flagship schemes/ missions namely, Rashtriya Krishi Vikas Yojana (RKVY) and National Food Security Mission (NFSM) also partly address soil health related issues.

Table 1. State-wise funds released under the scheme- National Project on Management of Soil Health and Fertility (NPMSH&F)

(Rs. in lakh)

Name of States	Amount released during 2008-09	Amount released during 2009-10	Amount released during 2010-11	Amount released during 2011-12	Amount released during 2012-13	Amount released during 2013-14	Total amount released
Andhra Pradesh	175.00	183.45	149.15	466.25	0.00	178.20	1152.04
Arunachal Pradesh	75.00	0	75.00	0	0.00	0	150.00
Bihar	0	904.69	342.91	0	0.00	0	1247.60
Chhattisgarh	0	0	59.40	0	0.00	72.45	131.85
Goa	05.00	0	0	0	0.00	0	05.00
Gujarat	0	0	0.0	186.25	138.32	0	324.57
Haryana	0	0	144.10	0	121.00	0	265.10
Himachal Pradesh	35.00	143.72	0	0	0.00	0	178.72
IISS, Bhopal	0	389.87	168.17	412.23	0.00	0	970.27
Jharkhand	0	255.80	0	0	0.00	256.61	512.41
Karnataka	125.00	270.57	0	0	0.00	0	395.57
Kerala	150.00	177.30	0	0	0.00	229.35	556.65
Madhya Pradesh	86.00	0	0	0	0.00	0	86.00
Maharashtra	65.00	280.00	60.00	0	289.72	76.75	771.47
Manipur	0	89.00	0	0	0.00	0	89.00
Meghalaya	0	60.00	0	0	0.00	10.50	70.50
Mizoram	60.00	12.50	0	0	0.00	40.50	113.00
Nagaland	15.00	0	0	0	0.00	0	15.00
Odisha	217.50	0	217.50	0	0.00	577.38	1012.38
Punjab	35.00	135.00	0	0	130.00	0	300.00
Puducherry	0.00	0.00	0.00	0.00	10.00	0	10.00
Rajasthan	415.00	267.60	408.62	0	0.00	0	1091.22
Sikkim	0	0	65.00	65.00	0.00	0	130.00
Tamil Nadu	0	250.00	0	0	50.00	180.63	480.63
Telengana	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tripura	0	136.50	0	0	0.00	0	136.50
Uttar Pradesh	15.00	240.00	0	0	0.00	0	255.00
Uttarakhand	25.00	0	0	0	20.68	0	45.68
West Bengal	163.75	0	0	0	0.00	0	163.75
MANAGE	0.00	0.00	0.00	0.00	21.75	9.25	31.00
Fertilizer cost	0	0	0	0	69.862	293.1805	363.0425
Total	1662.25	3796.00	1689.848	1129.73	851.332	1924.8005	11053.96

Recent Initiatives

The past initiatives have helped to an extent in promoting balanced and integrated use of plant nutrients by raising farmers' awareness and also by strengthening relevant infrastructure. However, the desired objectives remained only partially fulfilled. With lack of information on soil health, there is always a likelihood of neglect of nature and extent of certain nutrient deficiencies and excessive use of N. Irrational consumption of N skewed fertilizer consumption ratio in favour of N (Dwivedi 2012). Average $N:P_2O_5:K_2O$ consumption ratio at country level, was 4.6:2.0:1 during 2008-09, which got widened to

8.0:2.7:1 during 2013-14 (FAI 2015). This pointed to unusually higher consumption of N with reference to P and K. Further, the usage of secondary and micronutrients remained neglected. These developments signaled failure of interventions in right tracking yield to the desired levels. In fact, State Departments of Agriculture have been issuing SHCs to the farmers, since X Five Year Plan, and cumulatively they have issued over 70 million SHCs across the country. However, the performance varied from state to state, as given in table 2.

Table 2. State-wise soil health cards issued up to 2013-14

Zones	Name of the states (till March 2014)	Soil health cards issued (in lakh)
South zone	Andhra Pradesh	50.57
	Karnataka	62.31
	Kerala	21.72
	Tamil Nadu*	85.99
	Puducherry	0.07
	Andaman & Nicobar island	0.03
	Total	220.68
West zone	Gujarat*	66.03
	Madhya Pradesh	27.66
	Maharashtra	45.91
	Rajasthan	31.17
	Dadra & Nagar Haveli	0.05
	Chhattisgarh	6.83
	Goa*	2.51
	Total	180.16
North zone	Haryana*	21.96
	Punjab*	27.19
	Uttarakhand	3.42
	Uttar Pradesh	189.29
	Himachal Pradesh*	12.9
	Jammu & Kashmir	2.15
	Delhi	0.08
	Total	249.99
East zone	Bihar	13.11
	Jharkhand	1.83
	Odisha	25.95
	West Bengal	3.98
	Total	44.86
North Eastern zone	Assam	6.94
	Tripura	1.45
	Manipur*	1.86
	Meghalaya	0.95
	Nagaland	0.65
	Arunachal Pradesh*	1.97
	Sikkim*	0.97
	Mizoram*	3.07
	Total	17.85
	Grand Total	713.54

Further, these cards generally suffered from several weaknesses like absence of soil sampling protocols, neglect of secondary and micronutrient analysis, incomplete fertilizer and soil amendment prescriptions *etc*. apart from not being uniform across the country.

Soil Health Management (SHM) under National Mission for Sustainable Agriculture (NMSA)

Soil health management is one of the sub-missions of NMSA. It aims at strengthening of soil test infrastructure in the States including building their manpower capacity. It is operated as a centrally sponsored scheme and the pattern of assistance was 75:25 till the year 2014-15, which is now 60:40 between Centre and State with effect from the year 2015-16. The scheme components are detailed (Agricoop 2016) in table 3.

Table 3. Soil health components under NMSA

Components	Pattern of assistance
Setting up of new mobile/static soil testing laboratories (MSTL/ SSTL)	75% Assistance of total project cost to State Govt. for SSTL subject to a maximum limit of Rs 56 lakh per SSTL/MSTL.
Strengthening of existing SSTL/MSTL	75% Assistance to State Govt. subject to a maximum limit of Rs 30 lakh per MSTL/SSTL.
Training and demonstration on soil health management	Training to STL / FTL staff, field functionaries. Rs.25,000/- per training session for 20 participants or more.
	Training to farmers including field demonstrations; Rs. 10,000/- per training session for 20 participants or more. Rs. 20,000/- per front line field demonstration.
Creation of district-wise digital soil fertility maps	One time assistance to State Govt. up to Rs. 6.00 lakh per district subject to maximum of Rs. 50 lakh for one State per annum.
Providing Portable Soil Testing Kit to field level officers of State Govt.	Assistance @ Rs.15,000/kit
Promotion and distribution of micronutrients	50% of cost subject to a limit of Rs. 500/- per ha and/or Rs. 1000/- per beneficiary.

This paved way for launch of a comprehensive scheme for soil analysis across the country in a time bound and on a continuous basis and recommendation for suitable treatment of soils.

The New Initiative - Soil Health Card Scheme

This centrally sponsored scheme was launched by the Hon'ble Prime Minister on 19 February 2015. Integrated Nutrient Management (INM) Division of the DACF&W has been mandated to implement this scheme. This scheme has been approved for implementation during the XII Five Year Plan with an outlay of Rs. 568.54 crore (Rs. 5.6854 billions). It aims at issuing SHCs to each one of the 140 million farmers of the country once in a cycle of 3 years on a continuous basis. This will facilitate building up of the soil database of the country and monitor the changes occurring in the soil health status periodically. The scheme is further built on the principle of soil sample collection at decentralized level and analysis for 12 parameters *viz*., pH, EC, OC, N, P, K, S, Fe, Mn, Zn, Cu and B. Based on such comprehensive soil diagnostics, the SHC will recommend to the farmer the estimated dosage of nutrients that the soils need for producing optimum crop yield; and other soil amelioration interventions needed to be taken up to maintain the soil health. Such test-based recommendations will bring in rational and regulated use of fertilizers (Dwivedi and Dwivedi 2007). Twin benefits to the farmer, as a consequence, are improved per unit yields on a sustainable basis and reduced cost of cultivation.

The Department has also combined optimally in the scheme guidelines, the level at which sample should be collected for accurate results and the time and cost factors for nation-wide coverage. It lays down a grid of 10 ha in rainfed and 2.5 ha in irrigated areas for collection of soil samples. Based on the soil test results of a grid-generated composite sample, each farm holding will get a SHC. This translates into a total of about 253 lakh (25.3 million) soil samples to be tested in the laboratories. Though each cycle would be of three years, the maiden cycle is being squeezed to 2 years to facilitate quick soil test-based health management practices. Accordingly, the target has been split into 100 lakh (10 million) and 153 lakh (15.3 million) number of samples, respectively for the years 2015-16 and 2016-17 to generate 14 crore (140 million) SHCs over these two years. The subsequent cycle will, however, run over a period of 3 years each.

Objectives of the Scheme

i. To issue soil health cards every 3 years to all farmers of the country, so as to provide a basis to include deficient nutrients in fertilizer practices.

ii. To diagnose soil fertility related constraints with standardized procedures for sampling uniformly across states and analysis; and design Taluka/Block level fertilizer recommendations in targeted districts.

iii. To develop and promote soil test-based nutrient management in the districts for enhancing nutrient use efficiency.

iv. To build capacities of district and state level staff and of progressive farmers for promotion of nutrient management practices.

v. To strengthen functioning of Soil Testing Laboratories (STLs) through capacity building, involvement of students agricultural and science colleges and effective linkage with Indian Council of Agricultural Research (ICAR)/State Agricultural Universities (SAUs).

Components of the scheme: The components of the scheme (Table 4) are as described below:

Component (i): The Soil Health Card

The soil samples collected as per prescribed protocol will be analyzed for 12 comprehensive parameters that will educate and inform the farmers on the benefits of bal-

Table 4. Soil Health Card (SHC) Scheme Component-wise break up for 2 years

S.No.	Components	2015-16	2016-17	Total
1.	Soil Health Card (@ Rs 190 per sample) 2015-16 : 100 lakh samples 2016-17 : 153 lakh samples	190.00	290.70	480.70
2.	Training of technical staff (@ Rs 60,000 per training) 2015-16 : 500 2016-17 : 1000	3.00	6.00	9.00
3.	Financial assistance to farmers (@ Rs 2500/ha) 2015-16 : 80,000 ha 2016-17 : 1,60,000 ha	20.00	40.00	60.00
4.	Capacity building and use of ICT	8.09	5.07	13.16
5.	Mission Management	2.23	3.45	5.68
	Grand total	223.32	345.22	568.54
	GOI Share	111.66	172.61	284.27

anced use of fertilizers. A uniform SHC has been designed for the country, which will reflect the partnership between the Central and State Governments. It provides scientifically estimated nutrient and other soil amendment recommendations to the farmers on as many as 6 crops. Going forward, the software that facilitates generation of SHC in local languages and also provides electronic card repeatedly in case of loss of original card and also obtain recommendation for crops for varying yield targets.

Component (ii): Training for soil analysis

One-week hands-on orientation training for soil chemists, students/Junior Research Fellows (JRFs) for soil analysis and fertilizer recommendation in batches of 20 participants will be organized at SAUs/ICAR Institutes.

Component (iii): Financial assistance for package of nutrient recommendations

In the target villages, financial assistance will be provided to farmers for application of recommended doses to supplement organic and inorganic nutrients based on soil test.

Component (iv): Capacity building and regular monitoring and evaluation

Orientation for technical and line staff will be conducted by the States along with SAUs/ICAR institutions for facilitating implementation of balanced nutrient practices among the farmers.

Component (v): Mission Management

At national level and state level, Project Monitoring Teams (PMTs) will be put in place for monitoring the scheme.

Soil Sampling Protocols

The accuracy and utility of soil test results and fertilizer recommendations are a function of the quality of soil sampling. In fact, a poor soil sample is the biggest source of error in the soil testing programme. In order to collect representative soil samples, uniform sampling norms have been prescribed. The scheme envisages GPS enabled soil sampling from a grid of 2.5 ha in irrigated areas and 10 ha in rainfed areas. The samples will be drawn from a depth of 0-15 cm, following due collection protocols. The ideal time for collection of soil samples is between harvest of one crop and sowing/planting of the next crop. Thus, there will largely be two windows available for soil sampling *i.e.* April to June (pre-*kharif*) and October to November (pre-*rabi*).

Soil Analysis

Soil samples collected as per prescribed protocols will be analyzed for the following 12 comprehensive parameters:

Basic parameters	pH, EC and organic carbon
Major nutrients	Nitrogen (N), phosphorus (P) and potassium (K)
Secondary nutrients	Sulphur (S)
Micronutrients	Zinc (Zn), boron (B), iron (Fe), manganese (Mn) and copper (Cu)

In addition, agriculture and science colleges having soil testing laboratories are allowed to take up the task of soil testing. The students are to carry out the work of soil testing under the guidance and supervision of soil science faculty. To overcome staff shortage, testing of samples is allowed to be outsourced to private agencies. Alternatively, JRFs can be employed for testing of soil samples. The soil analysis has to be completed in the Soil Testing Laboratory within 3 weeks of receipt of soil samples. In addition to distribution of SHCs through post/extension staff, online delivery will also be facilitated. The nodal soil test laboratory shall prepare timelines for scheduling the soil health cards in the district in phases. The year-wise coverage of number of Taluks/Blocks will be prepared, so that continuous soil analysis takes place every three years. This rigour is essential so that the time gap between the previous and subsequent card that a farmer gets is not more than 3 years.

Soil Testing Infrastructure

There are 1244 soil testing laboratories (STLs) all over the country for analysis of the collected soil samples (Table 5). Majority of these labs are operated by the State Departments of Agriculture. Each district will require at least 2 labs to cope up with the soil testing demand. Government of India gives grants of up to Rs. 56 lakh (Rs 5.6 million) per lab for setting up new laboratories and this grant will be used for purchase of soil testing equipment. There also exists provision to upgrade the existing STLs to enable test for micro-nutrients. As of now, of the total 1244 STLs, only 454 are equipped to test all the targeted 12 parameters. In fact, the Government showed its willingness on building STL infrastructure in the year 2014-15 itself, *i.e.*, before the launch of SHC scheme. With sanction of funds for 105 new STLs and up gradation of 225 existing labs, the country will have a total of 1345 STLs over the next year. Of these 675 will be equipped for testing all the 12 parameters including micronutrients. Of the total installed analyzing

Table 5. Statement showing state-wise number of STLS in the country, their analyzing capacity, and utilization during 2013-14

S. No	Name of the State	No. of Soil Testing Laboratories				Total			Annual analyzing capacity (in '000')	Sample analyzed (in'000')	Capacity utilization (%)
		State Govt.		Fertilizer Industry							
		Static	Mobile	Static	Mobile	Static	Mobile	Total			
I	South Zone										
1	Andhra Pradesh	55	5	27	1	82	6	88	413.00	345.785	83.73
2	Karnataka*	56	0	6	2	62	2	64	295.66	194.81	65.89
3	Kerala	14	11	1	0	15	11	26	218.00	134.68	61.78
4	Tamil Nadu	30	16	1	1	31	17	48	5796.72	4823.54	83.21
5	Puducherry*	2	0	0	0	2	0	2	4.00	4.41	110.25
	Total	157	32	35	4	192	36	228	6727.38	5503.23	81.80
II.	West Zone										
6	Gujarat	132	2	4	1	136	3	139	1412.00	1199.13	84.92
7	Madhya Pradesh	50	7	2	4	52	11	63	378.00	346.52	91.67
8	Maharashtra*	123	23	8	4	131	27	158	2241.35	967.27	43.16
9	Rajasthan	34	22	1	2	35	24	59	536.00	402.69	75.13
10	Chhattisgarh	7	5	1	0	8	5	13	105.00	116.02	110.50
11	Goa	2	0	0	0	2	0	2	23.00	14.96	65.04
	Total	348	59	16	11	364	70	434	4695.35	3046.59	64.89
III	North Zone										
12	Haryana	35	3	2	0	37	3	40	365.00	247.89	67.92
13	Punjab*	54	12	2	3	56	15	71	631.50	282.11	44.67
14	Uttarakhand	13	3	0	0	13	3	16	106.54	95.23	89.38
15	Uttar Pradesh	255	18	5	3	260	21	281	4159.50	3404.58	81.85
16	Himachal Pradesh	11	4	0	0	11	4	15	125	124.38	99.50
17	J&K *	8	5	0	0	8	5	13	52.00	43.61	83.87
18	Delhi	1	0	0	0	1	0	1	5.00	0.46	9.20
	Total	377	45	9	6	386	51	437	5444.54	4198.26	77.11

contd...

Table 5 contd.

S. No	Name of the State	No. of Soil Testing Laboratories				Total			Annual analyzing capacity (in '000')	Sample analyzed (in'000')	Capacity utilization (%)
		State Govt.		Fertilizer Industry							
		Static	Mobile	Static	Mobile	Static	Mobile	Total			
IV	East Zone										
19	Bihar	39	0	0	0	39	0	39	230.00	248.71	108.13
20	Jharkhand	8	0	0	0	8	0	8	40.00	10.67	26.68
21	Orissa	17	6	1	0	18	6	24	270.00	255.06	94.47
22	West Bengal	10	8	0	2	10	10	20	112.40	60.43	53.76
	Total	74	14	1	2	75	16	91	652.40	574.87	88.12
V	NE Zone					0	0	0			
23	Assam *	7	4	0	0	7	4	11	84.00	60.76	72.33
24	Tripura	2	4	0	0	2	4	6	35.00	17.54	50.11
25	Manipur	4	4	0	0	4	4	8	40.00	1.37	3.43
26	Meghalaya	3	3	0	0	3	3	6	30.00	27.65	92.17
27	Nagaland	3	0	0	0	3	0	3	45.00	14.30	31.78
28	Arunachal Pradesh	5	3	0	0	5	3	8	9.00	7.86	87.33
29	Sikkim	4	2	0	0	4	2	6	37.00	39.87	107.76
30	Mizoram	3	3	0	0	3	3	6	27.00	25.00	92.59
	Total	31	23	0	0	31	23	54	307	194.35	63.31
	Grand Total	987	173	61	23	1048	196	1244	17826.67	13517.30	75.83

* Information not provided/ not provided correctly but taken previous years progress.

capacity of 17.83 million samples 13.52 million samples were analyzed during 2014-15 indicating an average capacity utilization of 75.8% (Dwivedi and Meena 2015). Therefore, the target of 10 million samples set for the year, 2015-16 will have to be accomplished utilizing existing infrastructure. However, quality of soil testing and timeliness of reporting will be crucial for distribution of targeted number of soil health cards to the farmers.

In order to maximise soil testing till such time as the States are able to build in-house infrastructure capability, some interim measures have been initiated. These include:

- Soil testing at ICAR institutes, SAU labs and KVK labs.
- ICAR to strengthen KVK capabilities by equipping them with soil testing kits/ mini labs
- States to operate their laboratories in 2 shifts.

Fertilizer Recommendations

Based on soil testing for 12 parameters, fertilizer recommendations will be generated for 6 crops (3 *rabi* and 3 *kharif*) of farmer's choice predominantly practiced in the area using Soil Test Crop Response (STCR) equations or State General Fertilizer Recommendations (GFR). The STCR equations for different crops and GFR have already been loaded in the Soil Health Card Portal. On entering the soil sampling details and soil test results, the soil health card can be automatically generated online.

Launch of Soil Health Card Portal

This application software has been developed by the National Informatics Centre (NIC) with support from INM Division of DACF&W and NRM Division of ICAR. The Soil Health Card scheme Portal was launched on 15 July 2015. The software has four modules:

a) Registration of soil samples.

b) Testing of samples in soil testing laboratories.

c) Fertilizer recommendation based on STCR equations or GFR.

d) Management Information System (MIS) Report

   - Software is registered as http://soilhealth.dac.gov.in and MIS reports module has been mailed to States along with username and password.
   - The software will enable the States to upload data on soil samples, soil test results, generation and distribution of soil health cards. The department officials need to make extensive use of this software. Also they are being supported by the Department through both hands-on and e-learning training programmes conducted by the Department. The officers-in-charge of SHC at the State and field levels have been participating in these training sessions.

Investments in Soil Health Management

The SHC scheme has been launched with an outlay of Rs. 568.54 crore (Rs 5.6854 billion) for the XII Five Year Plan. The component-wise budget allocation is indicated in table 5. The scheme that initially had a funding pattern based on the ratio of 50:50 has been revised to 60:40 between the Centre and the State, as per recent Government of India Order.

In addition, soil health management component of NMSA is being implemented with a budgetary outlay of Rs. 100 crore (Rs 1 billion) during 2015-16.

Expectations from Research Institutions

A strong linkage between ICAR research institutes, SAUs and State Departments of Agriculture is a pre-requisite for robustness of soil testing services and that of SHCs (Dwivedi and Meena 2015). This linkage, nevertheless, needs further strengthening since this has thus far been less than the desired level. As a result, the manpower engaged in STLs have neither got adequate training/orientation nor were the research advancements undertaken by the STLs. Following are some of the expectations from research institutions so as to achieve expected success in SHC and other schemes related to soil health management:

(i) ***Improvement in soil test methods:*** Reports indicate that the soil test methods frequently followed for determination of available N, S and B are not robust as far as reproducibility of results and predictability of crop response to fertilizers are concerned. There is a need to refine/improve these methods or replace them with alltogether new ones.

(ii) ***Fertilizer recommendation methods:*** The focus under the scheme is not only pre-season soil testing, but also on desired fertilizer recommendations by using well-developed and verified STCR equations. Although these equations are more scientific compared to general fertilizer recommendation (GFR), the same are presently not available for all crops and growing conditions. The STCR equations also give absurd recommendations for high yield targets due to their inbuilt limitations. The scientists should, therefore, work on other modern approaches like site-specific nutrient management (SSNM), and come out with tools for achieving this goal in pursuance of high yield targets.

(iii) ***Training/refresher courses for STL staff:*** ICAR Institutes/SAUs need to organize training/refresher training courses at regular intervals for STL staff. The staff will need hands-on training as also up-gradation of their knowledge and skills during such training programmes. Even the extension staff will need to be trained so that they can mobilize the farmers to participate actively in the movement, besides adhering to the sample collection protocol.

(iv) ***Preparation of popular literature:*** There is need to develop popular literature on aspects like importance of soil testing, balanced fertilizer use/integrated nutrient management, compost preparation *etc*. in local languages, and made available to the State

Departments of Agriculture for multiplication and distribution for enhancing awareness of farmers and extension functionaries. Effective and innovative deployment of ICT (Information, Communication and Technology) will aid transfer of knowledge. With increasing number of smart phones in rural areas, mobile based applications can be developed.

Conclusions

The present SHC scheme is an improvement over various attempts made so far for nurturing the country's soil health. For the first time, it is based on uniform protocol, comprehensive parameters, science based fertilizer recommendations and other soil amelioration interventions. Further, it is not a one-time affair, but is meant to be a continuous affair, helping thereby to track the changing status of soil health over time. Since the soil sample collection will be based on GPS coordinates, one can return to the same location for sampling in the subsequent cycles. Some scientists find the present SHC incomplete until a few biological parameters are included. As fresh soil is needed for analysis of most of the biological parameters, it is difficult to reach out such samples to the STLs and therefore, inclusion of these parameters is not feasible at this stage. Development of simplified test methods and establishing implications of biological (and even physical) parameters on fertilizer use decisions would help inclusion of some biological parameters, if essentially needed. Another important issue is the quality of SHC that depends on the quality of soil analysis carried out in the STLs. At present the condition and functioning of several STLs is below mark. With inadequate facilities/infrastructure and poor technical skills of the manpower engaged in these STLs, quality of soil analysis is a concern. There is urgent need to revamp the soil testing services and infuse necessary professionalism. Along with extension of STL network by establishing new labs, what is needed is to strengthen the existing labs with necessary equipments/support services, train human resource and assigning some accountability. Establishment of referral labs and samples exchange programmes are some measures to ensure quality of analysis. As most of the STLs operate under State Departments of Agriculture, any revamping of the service is possible only with the support of the State Governments.

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Soil Health Management

P. Dey

Notwithstanding the significant growth in agriculture during the last five decades, most of India's soil-based production systems are showing signs of fatigue. The conservative estimates show that the demand for food grains would increase from 257 million tonnes (Mt) in 2012-13 to 355 Mt by 2030. Contrary to increasing food demand, the factor productivity and rate of response of crops to applied fertilizers under intensive cropping systems are declining year after year. Currently, the nutrient use efficiency is quite low. For instance, it is 30-50% with nitrogen (N), 15-20% with phosphorus (P), 8-12% with sulphur (S), 2-5% with zinc (Zn), 1-2% with iron (Fe) and 1-2% with copper (Cu). Low nutrient use efficiency results in deterioration of physical, chemical and biological health of soils.

In India, substantial volume of literature exists on physical, chemical and biological properties of soils. However, past research investigated various parameters individually and typically in isolation of their joint influence on crop productivity. Also, assessment of soil degradation has been made and well documented in India. But its operational aspects like linking to crop production and upkeeping soil and environmental quality have hardly been addressed. Database generation for key indicators of soil quality is, therefore, required for different soil types, cropping systems, and management practices under various agro-eco-regions of the country for quick assessment of soil health dynamics.

The major challenges in 21st century are food security, environmental quality and soil health. Besides, shrinking land holdings and increasing cost of inputs necessitate induction and adoption of scientific use of plant nutrients for sustaining higher growth of crop productivity. The soil fertility and fertilizer use project initiated in 1953, following a study by Stewart in 1947, 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 then 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 (OC) or alkaline permanganate oxidizable N, as a measure of available N; sodium bicarbonate (Olsen's extractant) extractable P, as a measure of available P and neutral normal ammonium acetate extractable K, as a measure of available K. Muhr *et al.* (1965) described a set of critical values that characterized the nutrient availability as low, medium and 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 rice and wheat, carried out in the Division of Soil Science and Agricultural Chemistry at the 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 absorption by plants of native and applied nutrients, were ignored. The generalized fertilizer recommendations developed by the soil-testing laboratories were applicable to the medium fertility soils with an arbitrary adjustment (decrease or increase by 25-50%) for high and low fertility soils. An All India Coordinated Research Project on Soil Test Crop Response (AICRP on STCR) of the ICAR employed multiple regression approach to develop relationship between crop yield on the one hand, and soil test values and fertilizer inputs, on the other. As is well known by now that by knowing the analysis-based nutrient supplying capacity of soils, crop responses to added nutrients and amendment needs can safely be assessed. Soil test calibration across disparate locations, however, remains necessary for establishing firm relationship between the level of soil nutrients and crop response to fertilizers in the real life field situations.

Harnessing the Indigenous Technical Knowledge in Nutrient Management

As defined by the Convention on Biological Diversity, Article 8 (j), *traditional knowledge refers to the knowledge, innovations and practices of indigenous and local communities around the world; traditional knowledge is mainly of a practical nature, particularly in such fields as agriculture, fisheries, health, horticulture, and forestr*y. Farmers in different parts of the world, especially in poor and marginal indigenous groups of south Asia and Africa, are experimenting with the agricultural adaptation measures in response to climatic variability for centuries. There exists a wealth of knowledge on a range of measures that can help in developing agri-technologies to overcome climate vulnerabilities. Information available thus far points out 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). In one such practice for direct seeded rice, cowdung is powdered and mixed thoroughly with the soil after broadcasting of rice seeds and then planking (leveling the land surface after cultivation with wood log) is done. Since N mineralization is essentially a microbe-mediated process, powdering and mixing of cow dung hastens the process. Research has shown that such practices improve nutrient uptake by the young plants due to better mineralization of N from the manure due to perked up soil water holding capacity. Apparently, there is a need to harness and manage such knowledge and fine-tune it for harnessing the potential of modern tools and techniques.

Nutrient Management Approaches

Nutrient management in India over time can be summarised by abuse of N and disuse of K, generally coupled with overuse of P. Generalized recommendations for a State give rise to imperfections in fertilizer application practices. These, in turn, promote over/under use and imbalanced nutrient applications. Guided by the recommendations of the extension agencies, Indian farmers, in general, adopt following nutrient management methods:

Blanket Fertilizer Recommendations

These recommendations, prescribed for large areas, are generally advocated by different State Governments. These are based on crop responses over large areas without taking into account the spatial and temporal variability of soil in terms of plant nutrient supplying capacity. Although, in principle, these recommendations are to be updated periodically, in practice, these continue for decades. The result is over/under use entailing economic/yield losses. Above all, this is the source of poor nutrient use efficiency led rise in environmental problems. The blanket recommendations neither have flexibility to factor in farmer resource endowment nor provide readjustment space for guidance of marginal and small farm holders having limited resources. Due to less complexity in arriving at plant nutrient application, these recommendations find advocacy with Line Departments.

Fertilizer Application based on own/peer Perception

This mode of fertilizer application is based on resource availability and crop growth history of a location. Fertilizer price, commodity price, availability of water and fertilizers, access to market and risk perception (abiotic and biotic) are main determinants of this type of fertilizer application which usually leads to imbalanced use of plant nutrients. Peer perceptions especially that of progressive farmers are often adopted without considering farmers' own resource endowment. Sometimes it has been observed that peer-perceived overuse of plant nutrients is associated with social prestige especially in north Indian situations of Punjab and Haryana. One such example is detection of high available Zn status due to over-enthusiastic application of $ZnSO_4$ to overcome erstwhile poor status of available Zn under sodic (high pH soils) conditions.

Soil-test-based Fertilizer Recommendation

This science-led plant nutrient recommendation is based on analysis of representative soil samples, correlation and calibration to come up with fertilizer recommendation. In its subset, it may be based on nutrient indexing followed by categorizing soils into different fertility classes such as low, medium and high in terms of varying plant nutrient status, and developing recommendation for the medium fertility class. For soils testing low or high, the fertilizer recommendation for the medium fertility class is increased or decreased by 25% (Khosa *et al*. 2012). This classical approach is static and less wholesome, since it relies mainly on the soil test data and does not include information on the growing environment. Accordingly, some workers reported poor correlation between soil-test based data for available nutrients and crop yield (Dobermann *et al*. 2002) or the approaches for developing integrated nutrient recommendations from soil test data (Tandon 2012). In another subset, site-specific nutrient management (SSNM), which is basically a plant-based approach, was developed in the 1990s by IRRI in collaboration with national partners across Asia. The intent of this development was to address serious limitations arising from blanket fertilizer recommendations. The development of SSNM represented recognition that future gains in productivity and input-use efficiency required soil and crop management technologies that are more knowledge-intensive and tailored to the specific characteristics of individual farms and fields. A generalized SSNM approach was developed in 1996 (Dobermann *et al*. 1996) and subsequently tested in more than 200 irrigated rice farms across Asia. It focused on managing field-specific spatial variation in indigenous NPK supply, temporal variability in plant N status occurring within a growing season and medium-term changes in soil P and K supply resulting from actual nutrient balance. The approach required a data management option to predict soil nutrient supply and plant uptake in absolute terms in the high-yielding irrigated rice systems in Asia. A modified QUEFTS model (Janssen *et al*. 1990; Witt *et al*. 1999) was used for this purpose. It described the relationship between grain yield and nutrient accumulation as a function of climatic yield potential and the supply of the three macronutrients. In a situation of balanced nutrition, the QUEFTS model assumed a linear relationship between grain yield and nutrient uptake or constant internal efficiencies until yield targets reach about 70-80% of yield potential. As yields approach the potential yield, the internal nutrient efficiencies decline as the relationship between grain yield and nutrient uptake enters a non-linear phase. To model this in a generic sense required the empirical determination of two boundary lines describing the minimum and maximum internal efficiencies of N, P and K in the plant across a wide range of yields and nutrient status. A database containing more than 2000 entries on the relationship between rice grain yield and nutrient uptake was used to derive the generic boundary lines of internal efficiencies (Dobermann and Witt 2004). The balanced N, P and K uptake requirements for 1000 kg of rice grain yield were estimated from the respective envelope functions as 14.7 kg N, 2.6 kg P and 14.5 kg K, which is valid for the linear phase of the relationship between yield and nutrient uptake. The corresponding borderlines for describing the minimum and maximum internal efficiencies were estimated at 42 and 96 kg grain kg^{-1} N, 206 and 622 kg grain kg^{-1} P and 36 and 115 kg grain kg^{-1} K, respectively (Witt *et al*. 1999). The parameters were found to be valid for any site in Asia at which modern rice varieties with a harvest index of about 0.45-0.55 were grown. Another important subset, the targeted yield approach, wherein 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). This forms the basis for fertilizer application for targeted yields (Truog 1960). Among the various methods of fertilizer recommendation, the one based on yield targeting is unique in the sense that this method not only indicates soil test-based fertilizer dose but also the level of yield the farmer can hope to achieve if good agronomic practices are followed in raising the crop. The differentiation of significant multiple regression equations provides a basis for soil test-fertilizer requirement calibration for maximum yield per hectare, maximum profit per hectare and maximum profit per rupee invested on fertilizer. The resultant 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 fertilizer application helped in obtaining higher response and benefit: cost ratios over a wide range of agro-ecological regions (Dey and Srivastava 2013). Targeted yield concept strikes a balance between 'fertilizing the crop' and 'fertilizing the soil'. The procedure provides a scientific basis for balanced fertilization and balance between applied nutrients and soil available nutrients. In the targeted yield approach, it is assumed that there is a linear relationship between grain yield and nutrient uptake by the crop. It implies that a definite amount of nutrients are taken up by the plant for producing a predefined yield. Once this requirement is known for a given yield target, the corresponding fertilizer level is estimated by discounting for the contribution from soil available nutrients. Over the last several years, different Centres of the AICRP (STCR) conducted more than 4000 frontline demonstrations in in farmers' fields to confirm the validity of the STCR technology. Findings of these farmer field demonstrations clearly brought out the superiority of STCR-IPNS fertilizer recommendations for different crops over blanket recommendation and farmer's practice. Not only were the yields superior, but B:C ratio and net returns were also higher. Frontline demonstrations conducted under Tribal Sub Plan (TSP) in Assam, Bihar, Chhattisgarh, Gujarat, Himachal Pradesh, Jammu and 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. Even farmers with very little knowledge of modern agriculture could achieve the yield goals by practicing STCR technology within ±10% variations of the target set (Dey 2015). Of late, besides developing fertilizer prescription equations for hitherto untouched secondary nutrient S (sulphur), STCR has 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 P-pools in organic farming systems, has been developed.

Benefits of Soil Test based Targeted Yield Approach

During the previous four decades, the STCR project has generated numerous fertilizer adjustment equations for achieving targeted yields of important crops growing on different soils across varying agro-ecological regions of the country. These fertilizer adjustment equations have been verified through follow-up investigations and frontline demonstrations conducted across length and breadth of the country. In these trials soil test based fertilizer application helped to obtain higher response and B:C ratios (Table 1) (Dey 2012, 2015). It is evident that STCR-based approach of nutrient application has definite advantage in terms of increasing nutrient use efficiency over commonly recommended dose of nutrient application.

Table 1. Average response ratios (kg grain kg^{-1} 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
Groundnut	50	5.1	6.8
Soybean	17	9.6	12.2
Chickpea	35	6.1	9.4

Integrated Nutrient Management Strategies for Different Cropping Systems

The basic concept underlying the principle of integrated nutrient management (INM) is to maintain or adjust plant nutrient supply through all possible sources of plant nutrients to achieve a given level of crop production. The major objectives of INM are to: (i) reduce dependence on inorganic fertilizer sources, (ii) restore organic matter in soil, (iii) enhance nutrient use efficiency and (iv) maintain quality of physical, chemical and biological properties. Since, bulky organic manures alone may not be able to supply adequate amount of nutrients, nevertheless by adopting INM practices their value is harnessed in meeting the above soil health building goals. Long-term studies (Hegde 1992), have indicated that it is possible to substitute in part fertilizer N needs of *kharif* crop by FYM without any adverse effect on the total productivity of the major cropping systems such as rice-rice, rice-wheat, maize-wheat sorghum-wheat, pearl millet-wheat, and rice-maize. Because of low content, organic manures alone are not able to supply sufficient P for optimum crop growth. Then organic manures are known to decrease P adsorption/ fixation and enhance P availability in P-fixing soils. Organic anions formed during the decomposition of organic inputs compete with P for the same sorption sites and thereby increase P availability in soil (Iyamuremye *et al*. 1996) and improve utilization by crops. Reddy *et al*. (1999) observed higher apparent P recovery by soybean-wheat system on Vertisol with a combination of fertilizer P and manure. Based on these advantages, it is useful to popularize INM practices for achieving higher crop yields and fertilizer use efficiency. Examples of some INM strategies are compiled and presented in table 2.

Table 2. INM strategies for different cropping systems under various agro-climatic regions of India

Agro-climatic region	Cropping system	INM strategy
Western Himalayan Region	Rice–wheat	Green manuring of rice with *Sunnhemp* equivalent to 90 kg of fertilizer N along with 40 kg N ha^{-1} produces yield equivalent to 120 kg N ha^{-1}.
		In an acid Alfisol, incorporation of *Lantana camara* 10-15 days before transplanting of rice helped to increase N use efficiency.
Eastern Himalayan Region	Rice–rice	Use of FYM, compost, green manure, azolla, *etc*. met 25-50% of N needs in *kharif* rice and helped curtail NPK fertilizer use by 25-50%.
	Rice-mustard	With rice receiveing 10 t FYM ha^{-1} along with recommended NPK fertilizer, use of 20 kg N, 10 kg P_2O_5 and 25 kg K_2O ha^{-1} was sufficient for mustard.
Lower Gangetic Plains	Rice–wheat	Application of 75% of recommended NPK and 25% N through organic sources *viz*., FYM, green manure, *etc.* not only increased rice yields but also saved 25% NPK in succeeding wheat.
	Rice-potato-groundnut	Usefulness of 75% NPK with 10 t FYM ha^{-1} in rice and potato was established.
	Jute-based cropping systems	Use of 10 t FYM ha^{-1} enhanced fertilizer use efficiency in jute and helped saving 50% NPK.

Agro-climatic region	Cropping system	INM strategy
Mid Gangetic Plains	Rice–wheat	Application of FYM substituted 25% of recommended NPK for rice and improved fertilizer use efficiency and also fertilizer saved NPK use for following wheat also. Combined use of FYM, blue green algae and fertilizer improved nutrient use efficiency by 30-45% over chemical fertilizer alone.
Upper Gangetic Plains	Rice–wheat	Summer *Sesbania* geeen manure improved N use efficiency with a concomitant saving of 25% of NPK in rice as well as wheat. Application of 12 t FYM ha^{-1} in rice led to yield improvement equivalent to 60 kg N ha^{-1}, besides increasing the yield of succeeding wheat by 15%.
	Sugarcane–wheat	Combined use of 10 t FYM ha^{-1} and recommended NPK increased cane productivity by 8-12 t ha^{-1} over chemical fertilizer alone.
	Mustard–maize or rice	Reduced 25% NPK dose for mustard, if previous rice or maize was fertilized with 50% each of recommended NPK and FYM.
Trans-Gengetic Plain	Rice–wheat	Combined application of 12 t FYM ha^{-1} and green manuring could meet the entire N requirement of the high yielding rice. It also increased yield of following wheat by 10-15% due to residual effect.
	Pearl millet–wheat	Application of 50% recommended NPK as fertilizer + 50% N through FYM to *kharif* pearl millet followed by 100% NPK to wheat improved yields of both crops and NUE.
Eastern Plateau and Hills	Soybean–wheat	In order to get 2 t soybean and 3.5 t wheat, application of 8 t FYM ha^{-1} to soybean and 60 kg N+11 kg P ha^{-1} to wheat was necessary. Alternatively, application of 4 t FYM+10 kg N+11 kg P ha^{-1} to soybean and 90 kg N+ 22 kg P ha^{-1} to wheat was equivalent.
	Pulses	Integrated use of FYM at 2.5 t ha^{-1} and 50% recommended NPK fertilizers+*Rhizobium* inoculation helped in saving 50% chemical fertilizers equivalent.
Central Plateau and Hills	Soybean–wheat	For reaching a target yield of 2 t soybean and 3.5 t wheat ha^{1}, application of 8 t FYM ha^{-1} to soybean and 60 kg N+11 kg P ha^{-1} to wheat or application of 4 t FYM+10 kg N+11 kg P ha^{-1} to soybean and 90 kg N+22 kg P ha^{-1} to wheat produced equivalent results.
	Rice-wheat	Integrated use of 80 kg N ha^{-1} and 12 t FYM ha^{-1} enhanced N use efficiency over inorganic N fertilizer alone; FYM also produced residual effect in the following crop.
	Mustard	Substitution of 25-50% of chemical fertilizer through 10 t FYM ha^{-1} was possible to get higher yield and NUE.

Agro-climatic region	Cropping system	INM strategy
Western Plateau and Hills	Soybean–wheat	In order to get 2 t soybean and 3.5 t wheat, application of: either 8 t FYM ha^{-1} to soybean and 60 kg N+11 kg P ha^{-1} to wheat, or 4 t FYM+10 kg N+11 kg P ha^{-1} to soybean and 90 kg N+22 kg P ha^{-1} to wheat was required.
	Sorghum	It was possible to substitute 60 kg N through FYM or green *Leucaena leucocephala* loppings to get higher yields and NUE.
	Cotton	50% of recommended NPK could be replaced by 5 t FYM ha^{-1}.
Southern Plateau and Hills	Rice–rice	Application of 75% NPK+25% NPK through green manure or FYM at 6 t ha^{-1} to *kharif* rice and 75% NPK to *rabi* rice were equivalent.
	Sunflower	Application of 5-10 t FYM ha^{-1} in conjunction with 50% recommended dose of NPK, led to enhanced yield and nutrient use efficiency.
	Pulses	Integrated use of FYM or compost or biogas slurry at 2.5 t ha^{-1} with 50% recommended NPK helped in saving of 50% of chemical fertilizers.
East Coast Plains and Hills Region; West Coast Plains and Hills Region	Rice–rice	Integrated use of 80 kg N ha^{-1} and 12 t FYM ha^{-1} enhanced N use efficiency over inorganic N alone. There was also residual effect on the following rice crop due to FYM treatment.A successful inoculation of blue green algae @ 10 kg ha^{-1} provided about 20-30 kg N ha^{-1}.
Gujarat Plains and Hills	Mustard	It was possible to substitute 25-50% of chemical fertilizer through 10 t FYM ha^{-1} for getting higher yield and NUE.
Western Dry Region	Pearl millet	Combined use of N @ 20 kg ha^{-1}, 2 t cluster bean crop residue and 2 t FYM ha^{-1} increased NUE in pearl millet – legume system.

Source: Subba Rao *et al*. (1995); Mondal and Chettri (1998); Acharya *et al*. (2003)

In these studies economics and environmental benefits were generally given a go by. Value and acceptance of findings of these studies will enhance significantly, if inclusion of organic manures in the scheme of INM is non-competitive and has visible and measurable economic benefit. Such analysis needs to be a part of successful INM scheme.

Fertilizer Prescription Equation for Achieving Targeted Yield under Integrated Plant Nutrient Supply 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 biofertilizers. As the present requirement of chemical fertilizer nutrients is 32 Mt and only 22 Mt are being used, a shortage of 10 Mt 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 in soil physical, chemical and biological properties.

Use of Targeted Yield Equation and Development of Prediction Equation for Cropping Sequence

Nutrient availability in the soil after the harvest of a crop is strongly influenced by the initial soil nutrient status, the amount of fertilizer nutrients added, and the nature of the crop grown. To apply soil test-based fertilizer recommendations in a cropping system, the soils are to be tested after each crop, which is not always practical. Hence, it has become necessary to predict the possible soil test values after the harvest of a crop. It is done by developing post-harvest soil test value prediction equations making use of the initial soil test values, applied fertilizer doses and the yields obtained or uptake of nutrients following the methodology outlined by Ramamoorthy and Velayutham (1971). The post-harvest soil test values were taken as dependent variable, a function of the pre-sowing soil test values and the related parameters as yield/uptake and fertilizer nutrient application. The functional relationship is as follows:

Prediction Equation for Cropping Sequence

Prediction equations for post-harvest soil test values were developed from initial soil test values, fertilizer doses applied, and yield of crops/uptake of nutrients to obtain a basis for prescribing the fertilizer amounts for the crop succeeding the first crop in the cropping sequence. The method of calculation for prediction of post-harvest soil test values for cropping sequences is given below for use by each center:

$$YP/H = f\,(F, IS, \text{yield/nutrient uptake})$$

where, YP/H is the post-harvest soil test value, F is the applied fertilizer nutrient and IS is the initial soil test value. The mathematical form is

$$YP/H = a + b_1F + b_2\,IS + b_3\,\text{yield/uptake}$$

where, a is the absolute constant, and b1, b2 and b3 are the respective regression coefficients. During last fifteen years, the different centres of AICRP on STCR developed prediction equations by using the targeted yield equation for different cropping sequence like rice-rice, rice-maize, rice-wheat, maize-tomato, maize-wheat, potato-yellow *sarson*, rice-*ragi*, maize-Bt, cotton, wheat-groundnut, *okra*-wheat, rice-chick pea, soybean-wheat, rice-pumpkin, *bajra*-wheat, cotton-maize and soybean-onion. The predicted values can be utilized for recommending the fertilizer doses for succeeding crop thus eliminating the need of soil test after each crop. This provides the way for giving the fertilizer recommendations for whole cropping sequence based on initial soil test values.

Economic Analysis of Fertilizer Doses associated with Different Yield Targets

An appraisal of the effect of nutrients (NPK) applied on crop yield and B:C ratios, both under NPK alone and under IPNS for 15 agricultural and horticultural crops (Dey and Santhi 2014), showed that out of 66 crop × target combinations, the B:C was between 1 and 2 in 35% cases and between 2.1 and 3.0 in 62% cases. In 3% cases, B:C was above 3.0. lrrespective of the crops, higher yield has been recorded at higher yield targets over lower target coupled with higher net return and B:C. As in the case of yield, wherever three targets (low, medium and high) were tried, the B:C was relatively higher between low and medium target levels than between medium and high target levels both under NPK alone and IPNS. Once again, yield increase was higher with IPNS than with NPK applied through fertilizers alone. In this 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 organic manures improve soil physical and biological conditions besides contributing nutrients to plants. 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 vary several-fold even within the same location or from one lot to another.

Fertilizer Recommendations for Fixed Cost of Investment and Allocation under Resource Constraints

A new dimension to the value of the soil testing has been added by the concept of fertilizer application for targeted yield demonstration 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. When fertilizer availability is limited or the resources of the farmers are a constraint, planning for moderate yield targets, that are higher than the yield levels normally obtained by the farmer, provide opportunities to saturate more area with the available fertilizers and increase total production.

Linking Soil Fertility Maps with Nutrient Supply/Uptake Parameters for Spatial Fertilizer Recommendation

An attempt was made with joint venture of IISS, Bhopal and NBSS&LUP, Nagpur to create spatial fertilizer recommendation maps using available validated fertilizer adjustment equations (generated by STCR) and geographic information system (GIS). The district level soil fertility indexes of 10 districts of India were prepared, which can be used to generate balanced fertilizer recommendation for specified crops for entire district based on the average soil fertility status of that district. District-wise geo-referenced soil fertility maps were prepared using index values for N, P and K for 10 states. Corresponding equivalent soil nutrient values in respect of N, P and K were calculated from the index values. Reasonable limits for targeted yields were defined. The recommendations in the form of equations for targeted yields, developed by Subba Rao and Srivastava (2001), have been interlinked with the fertility maps. On application this recommendation system suggested for varied applications for targeted yields in different districts of states. This can be used up to field level also, if the farmer has the knowledge of his fertility status and the yield target. The maps can also be updated from time to time based on the soil test database. It can be further narrowed down to block/village level depending on the availability of appropriate information. These fertility maps can also be helpful in studying trends in the developing fertility status and can be correlated with fertilization practices of farmers of a particular region. These maps, however, only indicate the general soil fertility level of a district, since the data collected and used was not georeferenced. Subsequently, the scientists at ICAR-IISS took up a research project to prepare web-based soil fertility map for two districts *i.e.*, Hoshangabad and Guna of Madhya Pradesh by following multistage random sampling for collection of soil samples where *tehsils* were considered as strata in each district. The GIS-ased soil fertility map for N, P and K was prepared for Hoshangabad district and the soil test values were revalidated. The method has been found to be better and soil fertility can be monitored over a period of time.

Following the above approach, a soil fertility map of 175 districts was prepared. Fertilizer recommendation equations derived from the STCR studies *i.e.* soil nutrient efficiency (Es), fertilizer nutrient efficiency (Ef) and nutrient requirement (NR) of a particular crop are now being linked with the soil fertility values on the map which makes it possible to provide spatial fertilizer recommendation in the form of maps. The recommendations can be obtained by an extension agent/farmer simply by locating his area on the map.

Application of Information and Communication Technologies

Agricultural development and sustainability crucially depend upon the access of relevant information at right and real time (Dey *et al*. 2013). There is a vast scope of improving transfer of information and communication technology (ICTs) through public, private and non-governmental organizations supported by, marketing and community services. The ideal delivery model for these ICTs is envisioned to be a multi-pronged strategy involving institutions under National Agricultural Research System (NARS) to go online, share their contents, and rural information kiosks providing information access to the farmers. India has 37% of the world's ICT-enabled projects in rural areas. Agricultural resource information using GIS models, expert systems, and databases on successful technologies have critical role in governance and decision making by farmers.

On-line fertilizer recommendation systems – DSS
http://www.stcr.gov.in

The AICRP on STCR has developed a computer-aided model that calculates the amount of nutrients required for specific yield targets of crops based on farmers' soil test data (Majumdar *et al.* 2014). It is accessible on website: http://www.stcr.gov.in. This software 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. This application is a user-friendly tool. It will aid the farmer in arriving at an appropriate dose of fertilizer nutrients for specific crop yield for given soil test values (Figure 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 new technologies.

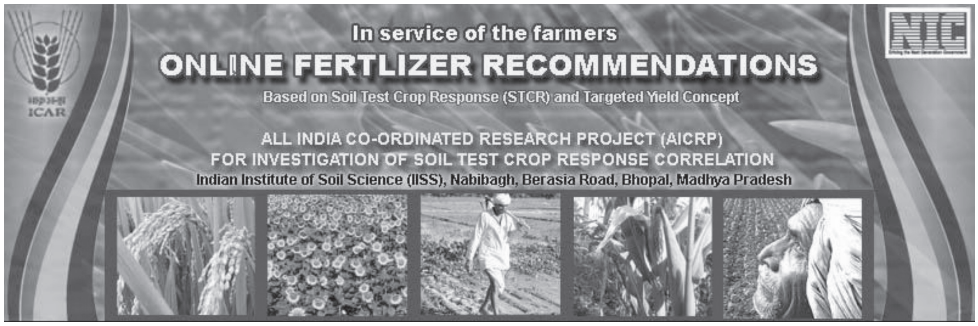

Figure 1. Internet enabled soil test based fertilizer application software

Computer software, including spreadsheets, databases, GIS, and others are readily available. The global positioning system (GPS) has given the farmer the means to locate position of his field within a margin of few feet. By tying position data with other field data mentioned earlier, the farmer can use the GIS capability to create maps of fields or farms. Sensors are under development that can monitor soil properties, crop condition, harvesting, or post-harvest processing and give instant results or feedback which can be used to adjust or control the operation.

DSSIFER

Decision Support System for Integrated Fertilizer Recommendation (DSSIFER) is a user-friendly software. Its updated version (DSSIFER 2010) encompasses soil test and target yield-based fertilizer recommendations through integrated plant nutrition system. This software was developed by the AICRP-STCR jointly with the 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, fertilizer doses can be prescribed for about 1645 situations and for 190 agricultural and horticultural crops along with fertilization schedule. If site-specific soil test values are not available, database included in the software on village fertility indices of all the districts of Tamil Nadu will generate soil test-based fertilizer recommendation. Besides, farmers' resource- based fertilizer prescriptions can also be computed. Therefore, adoption of this technology will not only ensure site-specific balanced fertilization to achieve targeted yield of crops but also result in higher response ratios, besides sustaining soil fertility. In addition, the software also provides technology for problem soil management and irrigation water quality appraisal. Above all, soil testing laboratories (STLs) of all the organizations can generate and issue the analytical report and recommendations in the form of Soil Health Card (both in English and Tamil), which can be maintained by the farmers over long run.

Nutrient Expert

Developed by International Plant Nutrition Institute (IPNI) and its partners, *Nutrient Expert®* is a tool that is based on the plant-based approach of SSNM (Pampolino *et al.*

2012). It utilizes information provided by a farmer or a local expert to suggest a meaningful yield goal for his location and formulates a fertilizer management strategy required to attain the yield goal. The required information about the production system is gathered through a set of simple, easily answerable questions that analyses the current nutrient management practices and develops guidelines on fertilizer management that are tailored for a particular location, cropping system and considers the organic inputs as a part of the system nutrient balance.

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

Recently the soil health card portal has been developed by Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and 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.

Conservation Agriculture and Soil Health

The three pillars of conservation agriculture (CA), *viz*., no tillage/minimum soil disturbance, residue retention/incorporation and diversified crop rotations, including legumes, do influence the soil nutrient dynamics. As a consequence of this positivity, Kassam and Friedrich (2009) even suggested that conventional soil analysis data may not necessarily be a valid basis of fertilizer recommendations for CA, since the available soil volume and the mobility of nutrients through soil biological activities tend to be higher than in tillage-based systems against which the existing recommendations have been calibrated. The authors also suggested that the nutrients and their cycles must be managed more at the system or crop mix level in a fully established CA system so that fertilization is not strictly crop-specific, rather nutrients are provided at the most convenient time during the crop rotation to maximize benefit. The importance of nutrient management in CA systems were well articulated in a recent article (Vanlauwe *et al*. 2014) where the authors argued that a fourth principle of CA – the appropriate use of fertilizer – is required to enhance both crop productivity and produce sufficient crop residues to ensure soil cover under smallholder conditions in Sub-Saharan Africa. They proposed fertilizer application as a separate principle for CA in contrast to other agronomic practices, including planting time, spacing and weeding regime, because fertilizer is essential for CA to work, while the sub-optimal implementation of other crop management practices do not lead to the failure of CA as such. They suggested that without acknowledging this fourth principle the chance of success for CA, especially with smallholder farmers, is limited.

Establishment and maintenance of soil health is inextricably linked to the achievement of effective and efficient nutrient management goal in CA. The CA builds a stratified layer of crop nutrients (especially P) on or near the soil surface. While reduced tillage and SOM build-up stable soil structure, the undisturbed structure is known to produce macropores and preferential flow channels that can direct nutrients (including P) downward into deeper parts of the soil profile. Conservation tillage can reduce overall N loss by reducing ammonium and organic N losses with sediment; however, it may not reduce N leaching in the nitrate form. Maintenance of soil health is the central to nutrient management strategies in CA systems within the prevailing ecological and socio-economic conditions. Nutrient management practices in CA systems cannot be reduced to simple physical input-output model. Nitrogen credits for legumes and manures can provide significant amounts of N to crops grown in rotation and need to be taken into consideration for N management in CA.

Rice-wheat system contributes major share towards food security of India. Resource conservation in rice-wheat system has the potential to address some of the emerging ill effects of nutrient mining, poor input use efficiency, pest pressure and yield stagnation (Dey *et al*. 2014; Singh *et al.* 2015). On ecosystem front, it has potential to maintain biodiversity, reduce emission and improve groundwater table. Both management and technological factors are important for creation of a win-win situation through adoption of resource conservation technologies. The topic of nutrient management in CA systems is a complex issue and needs attention from researchers for successful adoption of conservation agriculture practices at the farm level.

The researchable and policy issues which need urgent attention are:

- The subject of nutrient use efficiency in CA system should be viewed taking rice-wheat system as well as CA practices as a unit. Apportioning and application of the nutrients to crops in the system should take into account the nutrient requirements of and the nutrient residues left by the previous crop as well as developing customized fertilizers for CA system.
- Although the concept that conservation tillage and crop residue management enhance soil surface properties and prevent soluble nutrient runoff and soil erosion are valid, the use of reduced tillage limits fertilizer application to surface positions.
- Nitrogen management strategy through leaf tissue tests/LCC/NDVI-based indices needs to be worked out for CA system.
- Nutrients from residues are released over a number of seasons, and thus the nutrient contribution of residues must be worked out over several years. Therefore, there is a need to develop nutrient availability coefficients or constants through decay series approach for residues of different quality. Subsequently, these availability constants are needed to be calibrated against field studies using fertilizer equivalence approach.

- Even though some research has been carried out to identify SOM fractions acting as source and sinks for available plant nutrients, the effect of different CA management practices on the mobilization of these nutrients need to be studied further.
- For salt-affected soils, controlled drainage-sub-irrigation systems for recycling nitrate leaching from the soil profile and reduce nitrate lost in tile drainage may be advocated to all Land Reclamation Corporations.
- Phosphorus rates may need to be reduced for environmental reasons in high-risk areas. For this advocacy based on environmental P thresholds for CA systems protective of water resources may be done.

New Techniques for Estimation of Soil Fertility

One of the main obstacles to the application of the precision farming concept 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, most of the required analyses are time consuming, labour intensive and costly which in practice, make it un-economic to map the soil properties of a field with the required spatial and/or temporal resolution. Infrared spectroscopy has long been recognized as one of the most promising techniques to address this need (Nocita *et al*. 2014). Mid-infrared (MIR) Fourier transform (FT) and diffused reflectance infrared Fourier transform (DRIFT) spectroscopy have been used for the analysis of agricultural products (Reeves 2010) and soils (Janik and Skjemstad 1995). The first quantitative work with soils using MIR spectroscopy was reported by Janik and Skjemstad (1995) where calibrations for SOC and organic-N, and minerals including carbonates and EC were developed. Internationally, a considerable research effort is going on for developing near-infrared (NIR) and MIR calibrations for rapid estimation of soil parameters. ICRAF, Kenya reported that MIR spectroscopy in diffused reflectance mode (DRIFT) can be successfully applied to predict the composition of OM in soil and litter. Fast, consistent and economic estimation of soil characteristics is an important step in agricultural and natural resource management. Diffuse reflectance spectroscopy (DRS), encompassing both the near and middle infrared regions, is emerging as a new tool to obtain both qualitative and quantitative information of soil over the last two decade. In India, only a few spectral libraries in the visible and NIR region with different soil properties exist. The FTIR technique is a potential tool for the characterization of soil minerals.

Mini Land use Plan to Address Soil Health

The subtle difference between soil quality and soil health lies in the fact that while soil quality is the capacity of soil to function within the ecosystem and land-use boundaries, to sustain biological productivity, maintain the environmental quality and promote plant, animal and human health, the continuation of such capacity is in-built in soil health. In order to ascertain soil health, the region-specific strategies for improving productivity and profitability having common elements related to soil characteristics, topography and management practices need to be decided. In India, due to varying perceptions the management practices may differ across strata of farmers. Past management practices on uniform nutrient applications may have created excess nutrient accumulations in areas with low yield potential and nutrient deficits in areas with high yield potential. Hence, identification of uniform management zones is important and formulations could be developed for each management zone. An ideal land use plan to address soil health should essentially be built with due consideration to soil function and soil productive capacity as well as nutrient credit. A proposed outline for development of mini land use plan for appropriate soil health management is provided below:

Epilogue

Among the various methods of formulating plant nutrient recommendations, the one based on soil test 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 expect 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. However, there is no denying the fact that as on today we are mainly dealing with soil chemical fertility evaluation through soil testing, which is only the tip of the iceburg. Constraint analysis with respect to biological and physical properties has seldom been touched upon. These two factors account for about one-third of unaccounted variations in soil health assessment. There is a need to include some easily measureable biological parameter like dehydrogenase activity and physical parameter like penetration resistance. 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 on economic development. A positive incentive for private investment for promoting soil carbon sequestration is also necessary. *Soil thematic strategy* of EU, *Senate resolution on soil* of USA and *Soil policy* of the Netherlands are already in place; a comprehensive soil policy is overdue for India. 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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