Vision 2050

Indian Institute of Soil Science

(Indian Council of Agricultural Research)

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MINISTER OF AGRICULTURE &
FOOD PROCESSING INDUSTRIES
GOVERNMENT OF INDIA

MESSAGE

The scientific and technological inputs have been major drivers of growth and development in agriculture and allied sectors that have enabled us to achieve self reliant food security with a reasonable degree of resilience even in times of natural calamities, in recent years. In the present times, agricultural development is faced with several challenges relating to state of natural resources, climate change, fragmentation and diversion of agricultural land to non-agricultural uses, factor productivity, global trade and IPR regime. Some of these developments are taking place at much faster pace than ever before. In order to address these changes impacting agriculture and to remain globally competent, it is essential that our R&D institutions are able to foresee the challenges and formulate prioritised research programmes so that our agriculture is not constrained for want of technological interventions.

It is a pleasure to see that Indian Institute of Soil Science (IISS), Bhopal, a constituent institution of the Indian Council of Agricultural Research (ICAR) has prepared Vision-2050 document. The document embodies a pragmatic assessment of the agricultural production and food demand scenario by the year 2050. Taking due cognizance of the rapidly evolving national and international agriculture, the institute, has drawn up its Strategic Framework, clearly identifying Goals and Approach.

I wish IISS all success in realisation of the Vision-2050.

(SHARAD PAWAR)

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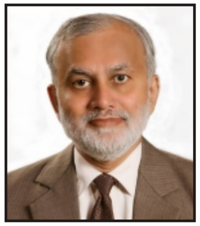

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सचिव एवं महानिदेशक
Dr. S. AYYAPPAN
SECRETARY & DIRECTOR GENERAL

Foreword

The Indian Council of Agricultural Research, since inception in the year 1929, is spearheading science and technology led development in agriculture in the country. This is being accomplished through agricultural research, higher education and frontline extension undertaken by a network of research institutes, agricultural universities and Krishi Vigyan Kendras. Besides developing and disseminating new technologies, ICAR has also been developing competent human resources to address the present and future requirements of agriculture in the country. Committed and dedicated efforts of ICAR have led to appreciable enhancement in productivity and production of different crops and commodities, which has enabled the country to raise food production at a faster rate than the growth in demand. This has enabled the country to become self-sufficient in food and emerge as a net food exporter. However, agriculture is now facing several challenges that are expected to become even more diverse and stiffer. Natural resources (both physical and biological) are deteriorating and getting depleted; risks associated with climate change are rising, new forms of biotic and abiotic stress are emerging, production is becoming more energy intensive, and biosafety concerns are growing. Intellectual property rights and trade regulations impacting technology acquisition and transfer, declining preference for farm work, shrinking farm size and changes in dietary preferences are formidable challenges.

These challenges call for a paradigm shift in our research approach to harness the potential of modern science, innovations in technology generation and delivery, and enabling policy and investment support. Some of the critical areas as genomics, molecular breeding, diagnostics and vaccines, nanotechnology, secondary agriculture, farm mechanization, energy efficiency, agri-incubators and technology dissemination need to be given priority. Multi-disciplinary and multi-institutional research will be of paramount importance, given the fact that technology generation is increasingly getting knowledge and capital intensive.

It is an opportune time that the formulation of 'Vision-2050' by ICAR institutions coincides with the launch of the national 12th Five Year Plan. In this Plan period, the ICAR has proposed to take several new initiatives in research, education and frontline extension. These include creation of consortia research platforms in key areas, wherein besides the ICAR institutions, other science and development organizations would be participating; short term and focused research project through scheme of extramural grants; Agri-Innovation fund; Agri-incubation fund and Agri-tech Foresight Centres (ATFC) for research and technology generation. The innovative programme of the Council, 'Farmer FIRST' (Farmer's farm, Innovations, Resources, Science and Technology) will focus on enriching knowledge and integrating technologies in the farmer's conditions through enhanced farmer-scientist interface. The 'Student READY' (Rural Entrepreneurship and Awareness Development Yojana) and 'ARYA' (Attracting and Retaining Youth in Agriculture) are aimed to make agricultural education comprehensive for enhanced entrepreneurial skills of the agricultural graduates.

I am happy to note that the 'Vision-2050' document of Indian Institute of Soil Science, Bhopal has been prepared, based on the assessment of present situation, trends in various factors and changes in operating environment around agriculture to visualize the agricultural scenario about 40 years hence and chalk out a demand-driven research agenda for science-led development of agriculture for food, nutrition, livelihood and environmental security, with a human touch.

I am sure that the 'Vision-2050' would be valuable in guiding our efforts in agricultural R&D to provide food and nutritional security to the billion plus population of the country for all times to come.

Dated the 24th June, 2013
New Delhi

(S. Ayyappan)

Preface

The Indian Institute of Soil Science (IISS) has emerged as a leader in basic and strategic research on soils in the country. It has achieved significant success in the areas of integrated nutrient management, impact on soil under long-term cropping, technology for preparation of enriched composts, soil test based nutrient prescriptions, generation of district-wise GIS based soil fertility maps, organic farming practices, carbon sequestration in soils, sink capacity of soils for heavy metal pollutants, recycling of wastes, soil microbial diversity and biofertilizers, quality standards for municipal solid waste composts etc. The institute has to take up the emerging challenges of increasing food-grain production and ensuring food and nutritional security from shrinking land resources, characterizing and conserving large soil-biodiversity for appropriate deployment in agriculture, achieving self reliance in crop fertilization through indigenous mineral and by-product sources, developing efficient technologies for waste recycling, maintaining soil quality and ecological balance, and developing energy efficient agriculture and sequestering carbon by reorienting it's research pursuits addressing the emerging issues viz., enhancing nutrient and water use efficiency; sustaining soil and produce quality; soil biodiversity and genomics, climate change and carbon sequestration; minimizing soil pollution etc. The first systematic effort to envision the challenges and opportunities and to formulate its own strategy was undertaken in the last year of 20th century by preparing 'Vision 2020'. The next attempt was after five years by preparing "IISS Perspective Plan 2025' to address changes that had taken place. Very shortly it was followed by Vision 2030. However, a need was felt to prepare a relatively longer-term vision. The present document, IISS Vision 2050 articulates the strategic framework for innovation-led sustainable productivity of soil resources with minimum environmental degradation.

I consider it our privilege to express our deep admiration and immense gratitude to Dr. S. Ayyappan, Director General, ICAR for his encouragement and guidance in bringing out this document, IISS Vision 2050. I am grateful to Dr. Alok Kumar Sikka, DDG (NRM) for giving valuable suggestions in the preparation of this vision document. I also thank Dr. B. Mohan Kumar, ADG (Agronomy), Dr. P.P. Biswas, PS (Division of NRM), and D.L.N. Rao (Network Coordinator, BF), for going through the document and giving valuable suggestions. My thanks are also to Dr. A.K. Singh, Ex-DDG (NRM) for his constant encouragement and suggestions on the issues and challenges in natural resource management. I wish to express my sincere appreciation to the Programme Leaders, Project Coordinators and Scientists of the institute who have contributed valuable information for their respective programmes. Special thanks are due to the constituted team of scientists for compiling and editing IISS Vision 2050 document.

01 April, 2013
Bhopal

(A. Subba Rao)
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Context

The Indian institute of Soil science was established on 16th April, 1988 at Bhopal with a mandate of "Enhancing Soil Productivity with Minimum Environmental Degradation". To accomplish the mandate of the institute, it has given the priority to soil health related issues faced by farmers and other stakeholders. Though the institute has made significant progress in the past, a need was felt to prepare this vision 2050 document to provide the institute a long term perspective and roadmap for future soil research.

The institute has made a significant progress in understanding soil chemical, physical and biological processes under long-term cropping, manure and fertilizer use. It has achieved significant success in the areas of integrated nutrient management, impact on soil of long-term cropping with different nutrient management practices and carbon sequestration research. Work on organic farming has led to package of practices for different crops. The savings on soil carbon, water, nutrients, energy and time due to the adoption of conservation tillage practices have been shown in soybean-wheat system. Gainful utilization of urban solid wastes and agro-wastes by converting them into value-added composts, including vermi-composting and phospho-sulpho-nitro- composting technologies have been achieved. Work on sink capacity of soils for heavy metals has led to limits for their loading in soils, quality standards of composts with respect to organics, nutrients and heavy metals suiting to Indian conditions were worked out and being used in the country for enforcing quality control. Exploitation of large soil bio-diversity of plant growth promoting rhizobacteria and rhizobia has resulted in isolation of valuable germplasm that is being utilized in biofertilizer manufacture.

Reorientation of soil research is required in view of the ever shrinking land resources for agriculture, deteriorating soil health and decreasing factor productivity. Even though India has made significant progress in food grain production, it could not maintain the requisite health of soil in doing so. About 121 million hectare of land is at present suffering from various kinds of land degradation, of which chemical degradation (22.76 million hectare) is prominent. There is an urgent need to restore productivity of this land for sustaining higher production. Fertilizer prices are increasing world over and there will be physical shortage of fertilizers in future. This is always coupled with the uncertainties in fertilizer availabilities since almost entire quantity of P and K fertilizers is imported either as finished products or intermediaries. The problem is further accentuated with the fact that current nutrient use efficiencies in India are quite low. They are 30-50% for N, 15-20% for P, 8-10% for S, 2-5% for Zn, 1-2% for Fe and Cu. We certainly cannot increase or sustain our productivity under such situations. We have to employ in future all possible mechanisms and means to improve nutrient use efficiencies involving developing and testing of nano-fertilizers, developing consortia based microbial formulations for mobilization of soil nutrients, and engineering of nutrient efficient crops using molecular biology and biotechnological tools. India has the highest number of livestock (15% of world) and second highest human population in the world. It is estimated that every million tonne increase in food grain production will produce 1.2-1.5 million tonnes of crop residue and every million increase in cattle population will provide additional 1.2 million tonnes of dry dung per annum. But currently, a large amount of animal excreta either remains unutilized or used as fuel in the form of dung cake. Future research has to be tuned to harness this vast organic resource. Efficient mechanism of urine collection and extraction of nutrients from this is another area that needs attention. The technology of nutrient extraction (struvite process) from urine is available elsewhere but needs to be tested and adapted in India. Also, a huge amount of municipal and solid waste is generated in the country which is dumped indiscriminately on land in peri urban areas causing environmental pollution. Though technologies are available for conversion, still a lot remains to be done in segregation technology and hastening the process of decomposition. Stronger microbes need to be cultured/engineered which could decompose otherwise resistant organic materials. With India's growth story, in future, the labour would become expensive and farm mechanization and automation would come in a big way. New practices like precision agriculture and techniques like nanotechnology and biotechnology are required that are not only labour and cost-effective but also practicable and relevant in the future context. The nutrient package of practices applicable today would need reorientation so as to suit micro-irrigation and precision agriculture.

Though India has the highest biodiversity in the world, we are not in a position to exploit it. Because, most of the soil biota at present are not culturable and hence cannot be deployed very easily in nutrient fixation, release and as biocontrol agents. The institute would have to strive hard to make a breakthrough in this area.

Similarly, indigenous mineral and by-product resources of nutrients need to be tapped for their efficient use in agriculture as the country cannot afford to continue the heavy subsidy paid on imported fertilizer materials. Climate change has become a reality and future research needs to be oriented in developing climate resilient agriculture. Also, very efficient and precise use of inputs and energy are the need of the hour. Tackling the above challenges definitely requires a long term vision and strategy along with a roadmap to address the above challenges and one that is dynamic to quickly adapt to any unforeseeable changes. The Institute is now marching ahead to face complex challenges of soil health and crop productivity issues and to harness domestic and global opportunities to overcome these for the welfare of the farmers, consumers and other stake-holders in the food-supply chain. Sincere efforts are being made to become a leading organization in the world in the field of soil science, which is vibrant also sensitive to the needs of stakeholders.

Challenges

Food security is one of the great global challenges of the 21st century. Soils, and their continuing ability to support the sustainable intensification of agriculture, will have to play a central and critical role in delivering food security. But, most of our important soil based production systems are showing the signs of fatigue. As a result, the partial factor productivity of fertilizers has declined in intensive cropping systems. The current status of nutrient use efficiency is quite low in case of N (30-50%), P (15-20%), S (8-12%), Zn (2-5%), Fe (1-2%) and Cu (1-2%) brought about by the deterioration in physical, chemical and biological health of soils. The major reasons for soil health deterioration are: wide gap between nutrient demand and supply leading to low and imbalanced fertilizer use; emerging deficiencies of secondary and micronutrients in soil, soil acidity, impeded drainage, soil salinization and sodification, etc. Fortunately, rapid scientific advancements and availability of new tools, techniques, and approaches promise technological breakthroughs to accomplish these difficult missions. A major challenge however, is "to develop improved strategies for halting and reversing soil degradation" if long-term productivity is to be secured. Enhancing sustainable food production and use efficiency of applied nutrients require integrated strategies for both land and water resources through rational utilization of both and addressing crucial management issues with more attention to basic and strategic issues.

Some of the specific challenges for which the institute has to prepare itself are given below:

(i) Ensuring food and nutritional security from shrinking land and water resources

Shrinking agricultural land is a stark reality. The per capita availability of agricultural land has declined from 0.48 ha in 1951 to 0.16 ha in 1991 and is likely to decline further to 0.08 ha in 2035 and even less by 2050 due to growth in human population and infrastructure required for tourism, transport, industry, and mining sectors etc. New threats like disposal of municipal and solid wastes on landfills are other uncertainties. Hence, the greatest production increase has to come through higher yields from unit area. To achieve this, among other things, we have to increase our water and nutrient use efficiencies by at least three times.

It is not only land, but the gross per capita water availability will also decline from 1820 m^3/yr in 2001 to as low as 1140 m^3/yr in 2050. The water demand in other sectors in comparison with irrigation is shooting up and the per capita availability of water for irrigation is declining. Hence, micro-irrigation technologies will come up in a big way. Currently, micro-irrigation is limited to horticultural crops, but it will be used in major food crops in future. This will pose a challenge to the institute to develop strategies and technologies to fertilizing the crops with drip irrigations/sprinkler irrigation etc.

In addition to quantity of produce, maintaining the quality of produce in view of the changing food preferences poses another challenge. India's nutritional intake patterns are fast changing. The consumption of food grains is decreasing in both the rural and the urban areas. On the other hand, the consumption of vegetables, fruits and oil crops, and animal products such as milk, poultry and eggs, is expected to increase. This means future research should aim at balanced plant nutrition that would supply quality food to humans and animals. Technologies to synthesize new foods, like creating cheese, meat and egg substitutes from plants will emerge. Eliminating micronutrient malnutrition among people would be a challenge which is now clearly manifesting due to deficiency of iron, iodine and zinc.

(ii) Characterizing and conserving soil-biodiversity

India is endowed with a wide variety of climates and soils and has a rich biodiversity in both fauna and flora, and there is an enormous wealth of microbial diversity that remains unexplored. It is estimated that although one third of fungal diversity of the globe exists in India, yet only 5% of the fungi have been characterized so far. Similarly only 1% of the bacteria are culturable. The uncultured soil microbial diversity represents a rich reservoir of microorganisms and genes that can be explored for a variety of applications. A vast amount of basic research is required for exploitation of large pool of genes in soils to benefit mankind. To assess the soil health of ecosystem, we will need to focus on functional biodiversity which relates the species in the context of ecosystem functioning. It will be a challenge to link the presence of a key species or functional groups and relate the same to ecosystem or community functioning. Developing efficient N fixers, P solubilizers and other nutrient mobilizers will be a continuing priority in the context of climate change as we will need to evolve stress adapted cultures that can function in the new environmental pressure.

(iii) Achieving self reliance in crop fertilization through indigenous mineral and by-product sources

Ensuring timely access to adequate mineral fertilizers is the key to agricultural development, food security, poverty reduction and nutritional security, especially in the low-income food-deficit countries like India. However, ensuring timely access to fertilizers in India is a challenge since the country has to largely depend on imported fertilizers for meeting out its consumption (Table 1). Further, the fluctuating oil and consequently the fertilizer prices in the international market have led to nutrient insecurity in Indian agriculture. Also, fertilizer imports result in a huge burden to the exchequer and a subsidy burden of thousands of crores of rupees to GOI. Although, India has 2000 million tonnes of glauconite, 16000 million tonnes of polyhalites, and 2000 million tonnes of silvite minerals which could make India self reliant in potassic fertilizers, the technology to convert these mineral resources into usable fertilizers is not presently available. Similarly, around 310 million tonnes of rock phosphates deposits are known to occur in India. These resources may increase considerably in future as better and state-of-the-art technologies will be used for prospecting mineral resources. Therefore, development of technology for utilization of these mineral resources as source of plant nutrients poses a great challenge.

Table 1. Import, Production and Consumption (000 tonnes) of primary nutrients

Nutrients	Import	Production	Consumption
N	5577	12288	17300
P_2O_5	4264	4364	7914
K_2O	2557	-	2575

Source: Fertilizer Statistics: 2011-2012, The Fertilizer Association of India, New Delhi.

(iv) Developing efficient technologies of waste recycling

(a) Municipal and Solid Waste (MSW)

A huge quantity of MSW is generated in India annually. These wastes are simply dumped into ground that not only occupies the valuable land resources but also poses a threat to the environment, besides causing health hazards to the citizens. The total waste generated in urban India is estimated to be 188,500 tonnes per day (TPD) or 68.8 million tonnes per year (TPY). A total of 366 cities in India which represent 70% of India's urban population generate 47.2 million tonnes per year (TPY) at a per capita waste generation rate of 500 g/day. At this rate, the total urban MSW generated in 2041 would be 230 million TPY (630,000 TPD) and would occupy an area equivalent to that of Mumbai, Chennai, and Hyderabad. Soil scientists and other environmentalists have to play a pivotal role in converting these wastes into valuable manure through proper composting technology.

(b) Organic resources/wastes from livestock/farming

Organic wastes are no more wastes. They are increasingly finding their use in power generation and other alternative uses. However, it would be prudent if these wastes are recycled back in to agriculture. At the present level of crop production, crops remove around 31 million tonnes of NPK, whereas the consumption of fertilizer is around 28 million tonnes which leaves a gap of 3 million tonnes. The projected food grain production of 457 million tonnes in 2050 would remove about 58 million tonnes of NPK with an addition of 48 million tonnes of fertilizer nutrients (if the current trend of fertilizer additions continues), leaving a gap of 10 million tonnes. This may be a potential threat to the soil quality and sustainable agriculture, implying the need to develop ways and means to recycle the organic wastes generated in agriculture.

(v) Tackling environmental contaminants and developing climate resilient agriculture

The total area that is suffering from various kinds of land degradation is estimated to be 120.72 million ha of which 104.19 million ha falls under arable land and 16.53 million ha is under open forest. It includes water erosion 82.57 million ha, wind erosion 12.40 million ha, chemical degradation 24.68 million ha, and physical degradation 1.07 million ha. To restore and maintain the land suffering from such disorders would be a challenge that needs immediate and long-term attention by adoption of various ameliorative measures to maintain soil quality.

Due to increased anthropogenic activities, soil is the sink for several pollutants like pesticides, herbicides, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, heavy metals and many inorganic salts. These pollutants adversely impact the soil physico-chemical environment, nutrient cycling/transformation processes, soil biodiversity, plant growth, food quality through contamination etc. Mining, manufacturing and the use of synthetic products (e.g. pesticides, paints, batteries, industrial wastes, and land application of city and industrial sludge) in future can result in heavy metal contamination of urban and agricultural soils. Excess heavy metal accumulation in soils is toxic to humans and other animals. This leads to introduction of toxic elements in the food chain and poses a serious threat to animal and human health. For this, regulations governing the maximum loading limits of heavy metals have been developed by a number of developed countries. India does not have any such regulation or guidelines to set heavy metal loading limits for land application of pollutants.

Besides heavy metals, a continuing effort will be required to better understand biochemical cycling of nitrogen and phosphorus; and their various fractions and contribute to knowledge on their transport within soil as well as to water bodies, monitor their levels in rivers and ocean so as to reverse their environmental pollution effects on aquatic resources. Such information will be required in future on regular basis for reporting on environmental audit and international and national environmental protection agencies.

Agricultural and food production in the coming years will adversely be affected by climate change, especially in countries like India that are already climate-vulnerable (drought, flood and cyclone prone) and that have low incomes and high incidence of poverty. Due to green house effect, global mean surface temperature is projected to rise between 1.8°C and 4.0°C by 2100. Emissions from the agricultural sector account for roughly 14 per cent of global greenhouse gas (GHG) emissions. Stabilizing global warming below 2 °C is considered necessary to avoid severely dangerous effects of climate change. Adaptation and management of the natural resources to climate change will be a big challenge for food security, and maintenance of ecosystem services. Meeting this challenge will require halving CO_2 emissions by 2050 compared with 1990 levels. Increasing soil carbon sequestration through improved cropland and livestock management, forestry and agro-forestry initiatives and tillage practices will be a challenge that needs immediate and long term strategic research. The challenge is not just the maintenance of organic C at the present level but to enhance its level by at least 15-20%. Thus, assessing soil organic carbon (SOC) accretions/sequestration under intensive cropping with different management practices would play an important role in long-term maintenance of soil quality. Inventorying the sources and contribution of other GHGs like methane and reactive nitrogen species and their flows in agriculture systems will be needed to contribute regional and global efforts at climate change mitigation efforts.

(vi) Developing energy efficient agriculture

Over exploitation of natural resources under intensive agriculture in the last five decades has resulted in acute degradation of underground water resources, soil health and environment. Concerns about stagnating productivity, increasing production costs, declining soil quality, declining water tables and increasing environmental problems are the major factors forcing us to look for alternative technologies. Energy requirement has increased many folds resulting in high input cost for the farmers. Hence, developing economical agricultural technologies for different agro-ecosystems is a challenge.

Operating Environment

The Indian Institute of Soil Science has been in existence for the last 25 years. As an R&D institute, with a strong base of soil science and related science professionals, it is well-placed to propose a science-led strategy on securing soils and food sustainability. With ever increasing demands and challenges, the IISS has to go on expanding the horizons of activity to suit the changing scenario.

There will be major demographic and occupational changes in India in the next few decades. An analysis of 163 countries indicated a relatively strong correlation (R=0.83 and R^2=0.7) between the ratio of non-performing population (NPP, or non agricultural) to performing population or agricultural population (PP) and urbanization indicators (FAO (2011) Country STAT for Sub-Saharan Africa, Rome.). The study also finds that the NPP/PP ratio changes are faster than the rate of urbanization. In India, the percentage of population in urban agglomerations of more than 1 million (% of total population) has increased from 6.69% in 1961 to 12.2% in 2010. We foresee that this will increase at a much faster rate in the coming four decades decreasing the agricultural population and consequently the labour engaged in agriculture substantially. Automation and farm mechanization would become inevitable. New management practices involving micro-irrigation coupled with nutrient delivery, precision agriculture, customized and specialty fertilizers, bio-molecules, bio-cultures and etc. would become a reality. The institute will have to develop sophisticated laboratories to keep pace with the changing scenario. Some new laboratories that are being planned are "Soil Biodiversity and Biotechnology Laboratory" and "Nanotechnology Laboratory". These laboratories will be equipped with state-of-the-art facilities to carry out most advanced research in soil science.

Climate change would increase the variability of agricultural production across all areas, with increased frequency of extreme climate events. Increases in the incidence of droughts and floods, which are dominant causes of acute food shortages in semi-arid and sub-humid areas, mean that the poorest regions with the highest levels of chronic undernourishment will be exposed to the highest degree of instability in food production. Also climate change is altering the distribution, incidence and intensity of animal and plant pests and diseases and may result in new transmission modalities and different host species. At the same time, agriculture will become more closely linked with energy markets through the production of bio-fuels from crops, introducing additional variability in agricultural commodity prices. A one degree Celsius increase in temperature may reduce yields of major food crops by 3-7%. Much greater losses are likely at higher temperatures for longer durations. Greater loss is expected in winter (rabi) than in the rainy season (kharif). Length of growing period in rainfed areas is likely to reduce, especially in the peninsular region. We also expect that high income growth and urbanization will continue to contribute to further changes in food consumption patterns. The total nutritional intake will continue to increase, but the share of grain products will diminish further. As much as 54 % of the total calorie supply will be derived from non-grain products by the year 2050, compared to the 36% at present. Also, the differences in urban and rural consumption patterns will still exist, but the gap will be much narrower by 2050. The institute is planning to develop a sophisticated "Soil Health and Produce Quality Laboratory" and "Conservation Agriculture and Carbon Sequestration Laboratory" that will cater to the research needs in the above area. Also, to fine-tune its research to the emerging needs the Institute would establish linkages and collaborations not only with other ICAR institutes and State Agriculture Universities (SAUs) but also with other stakeholders like ICMR, IITs, ICRISAT, and other institutes/agencies of national and international repute.

Investing in soil science to support food production and sustainable agriculture presents the institute with opportunities for international leadership in development, industrial and environmental policy arenas. Incorporation of a new generation of scientists and professionals who can integrate plant, soil, water and land management is critical. To foster innovation, the institute is preparing to induct scientists from other disciplines like Biotechnology, Economics, and Computer Science who will enable us to better deliver interdisciplinary solutions. There will also be a strong framework in place for more effective research-industry engagement within the country to secure the next generation of soils/food research through 2050 and beyond. The institute is also planning to purchase some high end equipment facilities/equipment to carry out advanced research.

New Opportunities

Over the last few decades, the advancement of science has produced new tools, techniques and technologies that can facilitate research in hitherto unexplored areas. Given below are some opportunities that can help us in meeting out the challenges.

(i) Availability of geo-informatics, sensors and nanotechnology

For the first time in history, we have technologies for global data collection at multiple scales. Combining these technologies with digital databases along with their incorporation into geospatial models should afford many opportunities to help us better understand soil ecosystems and associated problems in the areas of land degradation; crop cover, forestry, organic carbon and nutrient status of soils etc.

Nanotechnology may play an important role in future soil science research particularly in improving the input use efficiency and aid in decontamination of polluted soils. Now it is possible to engineer biogeochemical tools robust enough to operate in situ in soil via a nanotechnology methodology, combining techniques and methodologies from modern analytical chemistry. We can also conduct studies on conversion of naturally occurring plant nutrient containing minerals into nano form to enhance the availability of plant nutrients in soil and as soil amendment. Utilization of nano particles of indigenous rock phosphate, gluconite/waste mica, pyrite, calcite/dolomite and spheralite/smithsonite as potential source of P, K, S, Fe, Ca, Mg and Zn to the plant may solve much of our plant nutrient problems.

Visible-NIR spectroscopy is now available that is a non-destructive analytical technique and could be used for measurement of many soil properties simultaneously. These properties can be utilized for development of instruments or sensors for rapid and on-the go measurement of soil properties to be utilized in precision farming. Satellite imagery and spectroradiometers can help immensely in achieving the desired objectives.

(ii) Opportunities of deploying GMOs for efficient nutrient use

Now new molecular tools are available that allow root traits of plants to be more readily identified and manipulated. The use of 'sentinel' plants and organisms with marker responses to particular signals will also allow monitoring of soil system states, to gain better understanding of the chemical and biological functions in the specific scenarios. It can target the near root environment, which is the hotspot of chemical and biological activity. One area in which the institute has to develop scientific strength is environmental nanotechnology for improving nutrient use efficiency and aid in bioremediation efforts.

Biotechnology can offer solutions for improved up-take of P by use of microbial inoculants. Plant biotechnology is increasingly looking to the functional biogeochemistry of the rhizosphere as a target for further crop optimization. For example, a detailed and robust understanding of molecular scale biogeochemical processes associated with phosphorus uptake at and around plant roots can lead to the development of target-specific, 'smart' agrochemical agents that can be applied to stimulate P uptake.

(iii) Exploring and exploiting new indigenous nutrient resources

There is a vast potential of natural and industrial by-product resources in India that remain to be exploited. Mineral resources like polyhalite, glauconite, and silvite offer a great opportunity to make the country self reliant in K fertilizer production. Similarly rock phosphate resources can meet much of the fertilizer P demand. Phosphate can be strongly adsorbed by different inorganic materials. New research techniques can recover P from wastewater or from treated effluents that can further supplement the fertilizer P demand and also prevent it from dispersing and disappearing in the aquatic environment. Till now, a vast amount of human excreta is not utilized in the country. Urine separation techniques (eg. struvite precipitation) for direct use on agricultural land (e.g. energy crops) and for N and P recovery are now available.

(iv) Opportunities to deploy simulation and process based modeling

Understanding the relationship between plants, soil and water is the key in helping to develop and deploy different models for agro-ecology and production in different environments. Now it is possible to research and understand particular components of such systems at a laboratory and field scale. Data obtained at laboratory level can be integrated between disciplines and is scaled up to a field ecosystem or even to a regional and global scale.

Projections of climate change impacts on food supply are largely based on crop modeling. At present process-based crop models are available that can evaluate the impacts of climate change scenarios either at a local or at the global scale for different crop species. However, in future crop modeling studies could use a risk assessment approach by combining an ensemble of greenhouse gas emission (or stabilization) scenarios of regional climate models and of crop models, as well as an ensemble of adaptation options concerning both management practices and crop species/varieties.

The techniques like remote sensing and geographic information systems (GIS) at various scales combined with interactive computer models can be used to generate more consolidated information. They may also make possible the pattern recognition or "spatial-temporal organization" which may improve the understanding of soil variability. Also new measurement technologies i.e. Laser-induced breakdown spectroscopy, Mid- and near-infrared spectroscopy, and Inelastic neutron scattering to monitor soil carbon levels will aid in up-scaling processes. Computational simulation is a powerful tool to give decision support to alternative land use practices, crop systems, and agrochemical applications under different environmental scenarios. This methodology is an important over empirical approaches and gives better predictions for use in improvement of land use practices and production systems.

(v) High end export opportunity for organic produce

India has 15% of the world's livestock population and a great opportunity lies ahead for organic farming in the regions where the livestock density is higher. The Indian organic farming industry is estimated at about 900 million rupees (US$ 20 million) and is almost entirely export oriented (www.eximbankindia.com). According to Agricultural and Processed Food Products Export Development Authority (APEDA), a nodal agency involved in promoting Indian organic agriculture, about 6,792 tonnes of organic produces worth 712 million rupees are being exported from India (www.apeda.com). Ascertaining the scope of organic farming in the country in the context of geographical advantages and export potential of crops, with special reference to annual crops should receive top priority. This market of organic products is expected to grow globally in the coming years and high growth rates over the medium term (from 10-15 to 25-30 %) are expected. Organic farming is being advocated in certain areas and selected crops having export potential. Opportunities exist to devise organic produce protocols and package of practices for different agro-ecoregions.

(vi) Opportunity to promote conservation agriculture

Conservation agriculture is based on the principle of providing continuous soil cover (crop residues, cover crops), minimum soil disturbance, and crop rotations and has a high potential to increase productivity while protecting natural resources and environment. It is practiced on more than 75 million ha worldwide in more than 50 countries. It is estimated that over the past few years adoption of zero-tillage has expanded to cover about 2 m ha in India. The potential of C sequestration in C depleted soils of India is high with adoption of conservation tillage. It is also estimated that most parts of the country will receive higher rainfall in 2020, 2050 and 2080 than the current value, so this changing scenario can be converted to suitable opportunities in conserving and sequestering C in Indian soils bringing with it attendant benefits of improved soil structure, improved soil and water quality and reduced soil erosion.

vii) New Processing and recovery techniques

New technologies to minimize waste generation and maximize recovery of finite, high-value resources from wastes are now available. Such opportunities to create marketable resources of phosphorus from waste P is demonstrated by innovative companies that 'harvests' nutrients from municipal wastewater and uses them to produce fertilizer. Growing of algal biomass within wastewater treatment is an established practice and this can be additionally modified to recover nutrients from wastewater. The use of soil as a bio-filter is an important option for environmental management in developed countries.

Goals/Targets

The institute will focus on the following goals/targets for the next four decades to address the challenges delineated. The six goals that are fixed for the next four decades are:

1. Providing food and nutritional security by improving nutrient and water use efficiencies.
2. Harnessing biodiversity and genomics for efficient agriculture and maintaining ecological balance.
3. Self sufficiency in plant nutrient supply through utilization of indigenous mineral resources.
4. Clean and safe soil environment through waste recycling.
5. Soil quality/health management for sustainable agriculture.
6. Developing strategies for energy efficient and climate resilient agriculture.

Given below are the action points along-with the output that are expected from these activities.

1. Providing food and nutritional security by improving nutrient and water use efficiencies

	Action points	Output
i.	Developing technologies for efficient use of nutrients through efficient delivery employing precision agriculture tools, nanotechnology, and fertilizer fortification.	Enhanced nutrient and water use efficiencies
ii.	Mineral enrichment in food crops through efficient bio - fortification technologies.	Nutritional security
iii.	Developing dynamic expert systems of precise and timely input supply under varying soil-crop-climate and resource situations.	Yield optimization with reduced fluctuations
iv.	Developing micro irrigation based efficient nutrient delivery technologies under water limited environments.	Saving in fertilizer nutrients and water use
v.	Developing consortia based efficient microbial formulations for mobilization of soil nutrients/fixation of nutrients in biological systems.	Enhanced nutrient availability from biological systems
vi.	Engineering of nutrient efficient crops and varieties utilizing molecular biology and biotechnological tools.	Availability of nutrient efficient crops/varieties

2. Harnessing biodiversity and genomics for efficient agriculture and maintaining ecological balance

	Action points	Output
i.	Prospecting of large soil bio -diversity including characterization and testing of functional communities of soil micro-organisms.	New bio -fertilizers for efficient N fixation/ bio -control agents/growth promoting rh izo-bacteria etc shall be available.
ii.	Impact assessment of soil management practices on functional diversity of microorganisms involved in key microbial functions and soil health using genomics tools	Good soil management practices. Development of genomic s oil health indicator.
iii.	Development of a new generation of small, robust sensors using nanotechnology.	In situ characterization of microbial bio-diversity and soil health.
iv.	Identify microbial plant interaction processes in the rhizosphere under different stress situations.	Identification of strains suited to different stress situations for optimum functioning of soil system.

3. Self sufficiency in plant nutrient supply through utilization of indigenous mineral resources

	Action points	Output
i.	Developing new plant nutrient products from indigenous mineral resources using nanotechnology.	New fertilizer materials become available
ii.	Beneficiation of minerals and byproducts though microbial, chemical and thermal interventions	Value added mineral products and reduction in fertilizer imports.

4. Clean and safe soil environment through waste recycling

	Action points	Output
i.	Establishing quality standards for waste products and quality compost production	Safe utilization of wastes along with development of clean environment.
ii.	Development of faster microbial based technologies to manage agro/ industrial/ municipal waste for nutrient supply and recovery	Efficient waste recycling and nutrient recovery
iii.	Quality assessment of waste waters and its recycling through biologically mediated/ chemical processes.	Safe use of waste water for irrigation.

5. Soil quality/health management for sustainable agriculture

Action points	Output
i. Developing a workable index of soil quality assessment factoring the influence of different ph ysical, chemical and biological soil attributes and developing strategies for restoring resilience of degraded soils. ii. Database of threshold values of key indicators of soil quality and resilience for identification of degraded and likely to degraded lands due to natural as well as anthropogenic activity. iii. Formulating standards with respect to heavy metals for background level, maximum allowable level and intervention level to generation of information on atmospheric inputs. i. Microbial bioremediation/ phyto-remediation strategies for soils contaminated with heavy metals and agrochemicals.	Generation of best management practices in farms, input supply planning, and environmental monitoring.

6. Developing strategies for energy efficient and climate resilient agriculture

Action points	Output
i. Development of conservation agriculture practices for different farming situations.	Improvement in resource use efficiency and soil health
ii. Assessment and modeling carbon sequestration potentials of different soils and land use systems and development of standards for carbon trading in agro-ecosystems.	Enhancement in soil carbon stock and soil health along with mitigation of climate change.
iii. Monitoring long -term changes in soil quality and carbon sequestration under conservation agriculture/organic farming.	Sustainable soil health improvement

Way Forward

Historically the path of global agricultural development has been narrowly focused on increased productivity rather than on a more holistic integration of sustainable natural resource management (NRM) along with food and nutritional security. Therefore, Indian Institute of Soil Science foresees a holistic or systems-oriented approach, to address the difficult issues associated with the complexity of food and other production systems in diverse ecologies and locations of the country.

To address the future challenges and meeting the goals, the institute has to upgrade its infrastructure and human resources considerably and develop a continuous system to collaborate and establish linkages with all the possible stakeholders involved directly or indirectly with NRM, especially with those working on soil and water component.

To start with, the institute will be establishing four highly sophisticated laboratories to conduct advanced scientific research in Soil Biodiversity and Genomics, Nanotechnology, Soil Health and Produce Quality, and Conservation Agriculture and Carbon Sequestration. These laboratories will act as a node for the most advanced research and advisory in the country. These centers will be functioning in a networking mode by creating and fostering a liaison with the other institutes engaged in selected basic and applied sciences like IITs, ICMR, and CCMB since the two very important targets of research on soil genomics and making mineral and by-products usable in agriculture require close association with molecular biologists, geologists, metallurgical engineers, and chemical engineers. A close coordination will also be established with agronomists, agrochemical industry R&D, innovative chemistry, small and medium enterprises (SMEs), environmental consultants, water industry, regulatory agencies, and state departments of agriculture in developing framework and strategies in input use efficiency and environmental protection. The institute will also develop networks with farmer organizations, NGOs, and private sector to facilitate long-term natural resource management to enhance benefits from natural resources for the collective good.

Simultaneously, the institute will strengthen its scientific staff by inducting scientists from other disciplines like economics, computer science, and biotechnology, and keep them abreast with latest development in science by providing trainings continually as the new tools, techniques, and methodologies emerge. Some important areas where the institute scientists will be trained are genomics, environmental nanotechnology, waste recycling, precision farming as well on the instrumentation aspect.

A close coordination will also be established with information and database agencies so that the processes and techniques developed by the institute may quickly reach the users. For example, minimum data set of soil quality/resilience indicators would be linked to a digitized national database containing reference values for good and poor soil quality and resilience of different soil types under different land capability/land use classifications which will also provide expert opinion on sustainable management of the soil to the stakeholders.

An important future endeavour of the institute would be to strengthen human resources in the support of natural capital through increased investment (research, training and education, partnerships, policy) in promoting the awareness of the societal costs of degradation and value of ecosystems services. In this direction, the institute is planning to emerge in the form of an advanced centre and a deemed University to impart quality education to M.Sc. students and research scholars in the areas of natural resource management.

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