Vision 2050

Indian Institute of Soil and Water Conservation
(Indian Council of Agricultural Research)
218,Kaulagarh Road, Dehradun
Uttarakhand
www.cswcrtiweb.org

Printed : July 2015

संदेश

भारतीय सभ्यता कृषि विकास की एक आधार रही है और आज भी हमारे देश में एक सुदृढ़ कृषि व्यवस्था मौजूद है जिसका राष्ट्रीय सकल घरेलू उत्पाद और रोजगार में प्रमुख योगदान है। ग्रामीण युवाओं का बड़े पैमाने पर, विशेष रूप से शहरी क्षेत्रों में प्रवास होने के बावजूद, देश की लगभग दो-तिहाई आबादी के लिए आजीविका के साधन के रूप में, प्रत्यक्ष या अप्रत्यक्ष, कृषि की भूमिका में कोई बदलाव होने की उम्मीद नहीं की जाती है। अतः खाद्य, पोषण, पर्यावरण, आजीविका सुरक्षा के लिए तथा समावेशी विकास हासिल करने के लिए कृषि क्षेत्र में स्थायी विकास बहुत जरूरी है।

पिछले 50 वर्षों के दौरान हमारे कृषि अनुसंधान द्वारा सृजित की गई प्रौद्योगिकियों से भारतीय कृषि में बदलाव आया है। तथापि, भौतिक रूप से (मृदा, जल, जलवायु), बायोलोजिकल रूप से (जैव विविधता, हॉस्ट-परजीवी संबंध), अनुसंधान एवं शिक्षा में बदलाव के चलते तथा सूचना, ज्ञान और नीति एवं निवेश (जो कृषि उत्पादन को प्रभावित करने वाले कारक हैं) आज भी एक चुनौती बने हुए हैं। उत्पादन के परिवेश में बदलाव हमेशा ही होते आए हैं, परन्तु जिस गति से यह हो रहे हैं, वह एक चिंता का विषय है जो उपयुक्त प्रौद्योगिकी विकल्पों के आधार पर कृषि प्रणाली को और अधिक मजबूत करने की मांग करते हैं।

पिछली प्रवृत्तियों से सबक लेते हुए हम निश्चित रूप से भावी बेहतर कृषि परिदृश्य की कल्पना कर सकते हैं, जिसके लिए हमें विभिन्न तकनीकों और आकलनों के मॉडलों का उपयोग करना होगा तथा भविष्य के लिए एक ब्लूप्रिंट तैयार करना होगा। इसमें कोई संदेह नहीं है कि विज्ञान, प्रौद्योगिकी, सूचना, ज्ञान-जानकारी, सक्षम मानव संसाधन और निवेशों का बढ़ता प्रयोग भावी वृद्धि और विकास के प्रमुख निर्धारक होंगे।

इस संदर्भ में, भारतीय कृषि अनुसंधान परिषद के संस्थानों के लिए विजन-2050 की रूपरेखा तैयार की गई है। यह आशा की जाती है कि वर्तमान और उभरते परिदृश्य का बेहतर रूप से किया गया मूल्यांकन, मौजूदा नए अवसर और कृषि क्षेत्र की स्थायी वृद्धि और विकास के लिए आगामी दशकों हेतु प्रासंगिक अनुसंधान संबंधी मुद्दे तथा कार्यनीतिक फ्रेमवर्क काफी उपयोगी साबित होंगे।

(राधा मोहन सिंह)

केन्द्रीय कृषि मंत्री, भारत सरकार

Foreword

Indian Council of Agricultural Research, since inception in the year 1929, is spearheading national programmes on agricultural research, higher education and frontline extension through a network of Research Institutes, Agricultural Universities, All India Coordinated Research Projects and Krishi Vigyan Kendras to develop and demonstrate new technologies, as also to develop competent human resource for strengthening agriculture in all its dimensions, in the country. The science and technology-led development in agriculture has resulted in manifold enhancement in productivity and production of different crops and commodities to match the pace of growth in food demand.

Agricultural production environment, being a dynamic entity, has kept evolving continuously. The present phase of changes being encountered by the agricultural sector, such as reducing availability of quality water, nutrient deficiency in soils, climate change, farm energy availability, loss of biodiversity, emergence of new pest and diseases, fragmentation of farms, rural-urban migration, coupled with new IPRs and trade regulations, are some of the new challenges.

These changes impacting agriculture call for a paradigm shift in our research approach. We have to harness the potential of modern science, encourage innovations in technology generation, and provide for an enabling policy and investment support. Some of the critical areas as genomics, molecular breeding, diagnostics and vaccines, nanotechnology, secondary agriculture, farm mechanization, energy, 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. Our institutions of agricultural research and education must attain highest levels of excellence in development of technologies and competent human resource to effectively deal with the changing scenario.

Vision-2050 document of ICAR-Indian Institute of Soil and Water Conservation (IISWC), Uttarakhand has been prepared, based on a comprehensive assessment of past and present trends in factors that impact agriculture, to visualise scenario 35 years hence, towards science-led sustainable development of agriculture.

We are hopeful that in the years ahead, Vision-2050 would prove to be valuable in guiding our efforts in agricultural R&D and also for the young scientists who would shoulder the responsibility to generate farm technologies in future for food, nutrition, livelihood and environmental security of the billion plus population of the country, for all times to come.

(S. AYYAPPAN)
Secretary, Department of Agricultural Research & Education (DARE)
and Director-General, Indian Council of Agricultural Research (ICAR)
Krishi Bhavan, Dr Rajendra Prasad Road,
New Delhi 110 001

Preface

Meeting food demand of the country's growing population and sustaining our limited non-renewable natural resources for future generations were never so challenging. The National Agriculture Policy of India envisages a growth rate of 4% per annum to achieve a target of 377 million tonnes of food grain production by 2050. However, degradation of our finite land and water resources at a faster rate is resulting in loss of food, fodder, fibre and fuel-wood production potential, and affecting the livelihood and environmental securities of millions of people. Soil erosion by water is the most serious form of land degradation, resulting in loss of crop productivity by 0.2–10.9 q/ha (66% total production loss) for cereals, 0.1–6.3 q/ha for oilseeds (21% total production loss) and 0.04–4.4 q/ha for pulses (13% total production loss) estimated across all the states, which has a direct bearing on food security of the country.

The Indian Institute of Soil and Water Conservation (formerly known as Central Soil and Water Conservation Research and Training Institute), with the primary mandate of conservation of natural resources and having over 60 years of experience, has developed strategies for checking land degradation and improving land productivity on sustainable basis. It has successfully demonstrated a number of technologies in different agro-ecological regions in watershed mode through a network of eight Regional Centres in the country with headquarters at Dehradun. Multi-disciplinary research agenda of the Institute not only focuses on realizing higher productivity and ensuring food security, but also on maintaining and enhancing quality of natural resource base. The Institute also conducts short and long term capacity building and skill development training courses regularly for policy makers, NGOs, field functionaries and farmers in soil and water conservation and watershed management.

Rainfed areas account for 60% of India's net cultivated land. In the present scenario, even after the realization of India's full irrigation potential, around 40% of net cultivable area of 142 million ha will still remain rainfed. In the light of limited scope of increasing production from the irrigated sector, transforming rainfed farming into more sustainable and productive system through efficient use of natural resources provides the only viable alternative to the problem. This can be achieved through cutting-edge and socially acceptable conservation and production technologies, well supported by appropriate and forward looking agricultural policies for promoting all round development of agriculture sector focussing on water conservation and soil health protection. It is in this context that a visionary approach is necessitated for sustainable land and water management.

The present document 'Vision 2050' articulates perceived challenges in Indian agriculture in the next four decades, such as land degradation and soil erosion, production losses due to soil erosion, shrinking land resources, water scarcity, climate change hazards, and future needs of capacity building and skill development. It presents various redefined strategic research endeavours to tackle the challenges, so as to provide new research opportunities by harnessing the power of science. In the face of an expected future change scenario like extreme weather events and climatic uncertainty, the resource conservation technologies will be evaluated and refined for their adherence to a greener environment commensurating with the national GHG emission policy. Study on environmental flow is a must to sustain the eco-system components. Under a conflicting interest of the different stressors, it is essential to develop a synergy among the various sectors of water users. The headwater catchments which are the major contributor to the environmental flow, therefore, comprise a challenging unit to mend these conflicts through careful evaluation and planning of appropriate interventions. Often it is observed that lack of a focused approach to intervene in critical areas has wasteful implications on the budgetary allocations. Hydro-ecological modelling provides the opportunities to identify the priority areas for immediate attentions. Policy initiatives and guidelines adaptable to a larger paradigm of natural resource management is a challenge to be seen in the future. However, linking of rivers may alter many of the hydro-ecological challenges now foreseen with respect to agricultural development.

There are a number of gaps and inconsistencies in existing data bases and information systems on natural resources. These gaps need to be bridged by inventories of land and water resources for taking informed decisions and implementation. New frontiers of research tools and procedures shall be seamlessly utilized in the field of conservation and management of soil and water resources for improving productivity and innovating cost-effective technological solutions to improve their quality and quantity. All research efforts will leverage the potential of frontier sciences like watershed management technology with emphasis on bio-industrial watersheds, bio-engineering, rainwater harvesting, nanotechnologies, decision support systems, artificial intelligence, information and communication technology, remote sensing, geographic information system, global positioning system, and process based hydrological models. These frontier sciences and techniques would be well integrated with on-going and future agricultural research endeavours and traditional knowledge base for improving research efficiency, targeting the better technologies, and identifying production and marketing environments. Various interests of different stakeholders in natural resource management and diversification would also be addressed and realized.

Pathways to achieve stated goals would include technology solutions based on decision support systems and expert systems for watershed planning and management, rainwater harvesting and energy-efficient micro irrigation systems, artificial groundwater recharge measures, identification of soil erosion hot spots for precision conservation, impact of soil erosion on productivity, soil organic carbon dynamics and appropriate soil and water conservation practices, including ITKs on soil & water conservation, use of nanotechnologies in resource conservation, and correcting point and non-point contamination of water bodies from watersheds for increasing land productivity and soil health. Multi-disciplinary integration of future research and development agenda will be promoted through establishment of Advanced Skill Development Centres on soil and water conservation and watershed management, up-gradation of the Institute to a Deemed University, strengthening national and international collaborations, and convergence with national programmes and corporate social responsibility initiatives.

I am highly indebted to Dr. S. Ayyappan, Secretary, DARE and Director- General, ICAR, New Delhi for his foresight, valuable guidance and consistent encouragement for developing this vision document. I express my gratitude to Dr. A.K. Sikka, Deputy Director General (NRM), ICAR, New Delhi for his valuable suggestions and guidance in finalizing the approaches and strategies presented in the vision document. Constructive suggestions offered by members of RAC, IMC, web reviewers and scientists of NRM division, ICAR are greatly appreciated. I sincerely thank all scientists of the Institute for bringing out this document in the present form within the stipulated period.

(P.K. Mishra)
Director, IISWC

Contents

Context

In 2050, the estimated total food grain demand of 377 Mt of some 1.6 billion people (about 33% more from now) will have to be met in our country (Amarasinghe *et al.*, 2007). Sustainable and increased productivity depends solely on natural resources of land, water and vegetation, which need to be judiciously managed to meet the growing needs of food requirements and maintain environmental security for our future generations. Shrinking and degrading natural resources, and changing climate, however, limit the ability to attain or sustain the consumptive lifestyle that is commensurate with expected increase in income levels (Fig. 1). Soil erosion coupled with soil health deterioration, low organic carbon content, micronutrient imbalance, depleting moisture and water levels, water pollution, and poor water and nutrient use efficiencies must be reversed and improved through scientific knowledge-based participatory approaches.

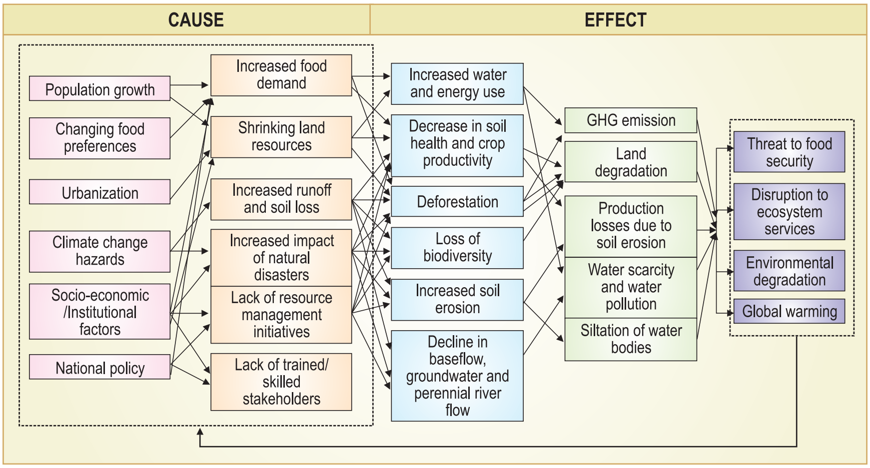


Fig. 1 Complex process of resource degradation and its driving forces

Status of land degradation

About 121 million ha land of India is degraded, mainly due to water erosion (83 million ha) (ICAR and NAAS, 2010). Among the negative impacts of soil erosion by water, the loss in crop productivity, disruption of nutrient cycle, alteration in water and energy balances, pollution of water bodies, deterioration in water quality, reduction of reservoir capacity, loss of biodiversity, and natural disasters like floods and droughts have a strong bearing on the national food and environmental security. Further, erosion vis-à-vis climate change studies indicate that increased rainfall amount and intensities will lead to greater rates of erosion. From this, it appears that by 2050 about 66 M ha under the slightly eroded class (5-10 t ha^{-1} yr^{-1}), which mostly covers croplands, will be additionally affected by higher rates of erosion due to climate induced changes in rainfall. This will result in significant increase in water erosion induced land degradation area from the current levels, unless ameliorative measures are undertaken in a strategic manner.

Growth induced demand for natural resources

India presently supports world's 18% human population and 15% livestock population on world's 2.4% land mass and 4.2% fresh water (NAAS, 2009), and the pressure on these finite resources is swelling due to ever increasing population. Rise in human population is linked to rise in demand for water, with agriculture being the major consumer. Per capita utilizable water for various purposes would decline, while the per capita water demand in different sectors will increase in due course. Consequently, share of agriculture sector in the total water use may reduce from 78% at present to 65-68% in 2050 (Dhingra and Ramaswamy, 2011) due to competing demands from other sectors. Per capita net sown area availability has declined below the prescribed threshold limit of 2.0 ha of unirrigated land or 1.0 ha of irrigated land required for a family of five to six members. To ensure food security, the average productivity of all food grains needs to be more than doubled from current 1.75 t/ha to achieve the estimated production target of food grains.

Conservation - key to sustainability

Managing soil and water resources, including degraded ones, to meet growing human and animal needs in terms of food, fibre, fodder, timber and fuel, therefore, is considered of paramount importance in the present context as well as of the future. Rainfed areas, which constitute about 60% of the net cultivated area, contribute only 42% to the total food production, while 39% of the irrigated area accounts for 58% of total output (GOI, 2011) to the national food basket. However, rainfed areas offer great potential for agricultural growth. The challenge before the Indian agriculture, therefore, is to transform rainfed farming into more sustainable and productive systems through efficient use of natural resources. For this, harnessing the potential of integrated farming systems, integrated nutrient management, and integrated water management needs to be undertaken from conservation point of view through location specific technologies in the form of Integrated Watershed Management Programme (IWMP) in rainfed agro-eco-system.

Global scenario on natural resource management

Resource degradation is recognised as a major problem in all parts of the world. The Millennium Ecosystem Assessment observed that 15 of the 24 ecosystem services they evaluated have been degraded over the past half century. A rapid and continuing rise in the use of fossil fuel-based energy and an accelerating use of natural resources are continuing to affect key ecosystem services, threatening supplies of food, freshwater, fuel wood and fish. More frequent and severe weather disasters, droughts and famines are also impacting communities around the world. Recent estimates indicate that out of world's total land area of 13.5 billion ha, the share of highly degraded land is 25%, moderately degraded land is 8% and land that is improving is 10% (FAO, 2011). Rothamstead opines that under business as usual scenario, the current soils that are in agricultural production will yield about 30 percent less than they would do otherwise by around 2050 (www.publications.parliament.uk/).

World Business Council for Sustainable Development in its vision for achieving a sustainable world by 2050 proposed multiple actions on a number of critical fronts. These include incorporating the costs of externalities, starting with carbon, ecosystem services and water into the structure of the marketplace, doubling agricultural output without increasing the amount of land or water used, and halting deforestation and increasing yields from planted forests (WBCSD, 2010).

Thus, conservation agriculture involving resource conservation technologies has emerged as a new concept for sustainable management of natural resources. In global scenario, while FAO proposed no-till conservation agriculture as an important strategy to improve food security by increasing productivity and reducing resource degradation, integrated rain water harvesting (RWH) is also increasingly viewed as an integral part of water cycle

management. Modern techniques of rain water harvesting and ground water recharging, and micro-irrigation have been considered vital in utilizing the existing resources and expanding irrigation in a viable manner. In coming decades, role of crop diversification, including agro-forestry and horticulture technologies, has been focussed for moderating the effect of droughts and as a contingency planning in the back drop of global warming and climate change. The concept of participatory watershed management has emerged as a new paradigm for efficient management of land, water and other natural resources for sustaining production while protecting the environment. Its beneficial effect on ground water recharge, crop yields, biomass production, employment generation and overall improvement in socio-economic conditions of rural poor has been documented widely and considered as a key for food and livelihood security in coming decades.

R&D in resource conservation

India was among the first few countries to have taken timely cognizance of the enormity of problems of soil erosion due to rainwater. Since the establishment of Soil Conservation Research, Demonstration and Training Centres during the 1950s in different problem areas of the country and their reorganization into the present set up of Indian Institute of Soil and Water Conservation (erstwhile known as Central Soil and Water Conservation Research and Training Institute (CSWCRTI)) in 1974, the R&D activities of the Institute and its Centres have continuously focused on evolving strategies/technologies for soil and water conservation, and watershed management. The Institute has evolved technologies for rehabilitation/reclamation of ravines, landslides, sloping lands, mine-spoils and torrent affected areas. The Institute has developed a number of resource conserving technologies for arable and non-arable lands, which have the potential to check land degradation, minimize soil erosion, preserve soil fertility, sustain productivity in the long run, conserve rainwater *in-situ*, mitigate droughts, moderate floods downstream and ensure environmental security.

The concept of bottom-up participatory integrated watershed development, which was evolved and demonstrated by the Institute in the 1970's, has emerged as a new paradigm for efficient management of land, water and other natural resources. The impact of watershed management programmes in flood/drought moderation, groundwater augmentation, increased biomass production, employment generation, and improvement in socio-economic conditions was amply demonstrated through Institute's model watershed projects. The concept is now being formally up-scaled through various schemes of integrated watershed development at national level by government agencies and NGOs.

'IISWC Vision 2050' document articulates many key challenges of next four decades and appropriate strategies to address them through a roadmap for conservation and management of soil and water resources of the country to achieve sustainable production by developing technologies for controlling land degradation and enhancing productivity on sustainable basis thereby ensuring food, environmental, economic and livelihood security to agrarian communities of the country.

❑

Challenges

Conservation of natural resources is a very important issue for sustainability of food security. Shrinkage and deterioration of natural resources like land, water, biodiversity, forests, and climate change, including global warming, are threatening sustainability of our food and nutritional security. Further, Indian agriculture is largely weather dependent, and hence is full of uncertainties. Because of this and other factors, new issues keep emerging, and there is a continuous need to find solutions through need based research and development programme.

Land degradation processes are on-going over large part of the earth. Most of the degradation is due to soil erosion and biodiversity losses in less populated areas, while water shortage, soil depletion and soil pollution are most common in agricultural areas. It takes several decades to undo the damage done to lands. The impact of this degradation is felt most in areas with a high incidence of poverty. Agricultural lands used for cropping and livestock rearing are more susceptible to degradation than non-agricultural lands. Land use, and associated inputs and management, are indeed the main direct causes of land degradation.

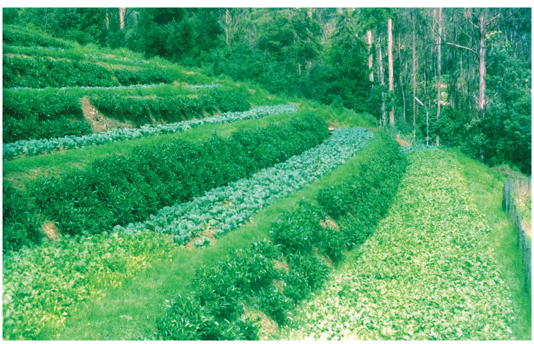
As per a FAO study, food consumption levels in India are projected to increase from current level of 2400 kcal/per capita/day to about 3000 kcal/per capita/day and demand for cereals to 243 Mt in 2050, an increase of 0.9% per year. Over the same period, cropping intensity in India is also projected to increase from 101% to 104% in rainfed areas and from 127% to 129% in irrigated areas. Rainfed crop yields are expected to increase to 2.0 t/ha and irrigated cereal yields from 3.5 to 4.6 t/ha in 2050 (Singh, 2009). By 2050, cereal production in India is projected to increase by 54% and production of potatoes, fruits and vegetables, vegetable oil, sugar and meat (except chicken) is projected to more than double, production of milk to triple, and production of eggs and chicken to increase even more rapidly. Presently, demand for high-value commodities (vegetables, fresh fruits, milk and fish) is increasing faster than for food grains due to rising per capita income and changing food preferences, causing a serious supply-demand imbalance, which needs drastic modification in farming systems being practiced on our limited agricultural lands. However, if our land and water resources continue to be degraded, the country is unlikely to fulfil the above projections/requirements. Rather, production losses will be accelerated due to land degradation and mismanagement of natural resources.

Land degradation and soil erosion

In India, about 68.4% (83 million ha) of total degraded land (121 million ha) is affected by water erosion of moderate (>10 t ha^{-1} yr^{-1}) to very severe (>80 t ha^{-1} yr^{-1}) intensities, followed by chemical degradation (25 million ha), wind erosion (12 million ha) and physical degradation (1.1 million ha) (ICAR and NAAS, 2010). Water erosion is the major threat to soil quality and quality of runoff water. It results in loss of organic carbon, nutrient imbalance, compaction, decline in soil bio-diversity, and contamination with heavy metals and pesticides. As per recent estimates by IISWC (erstwhile CSWCRTI), annual soil loss rate in our country is about 15.35 t ha^{-1}, resulting in loss of 5.37 to 8.4 million tonnes of nutrients, reduction in crop productivity, occurrence of floods/droughts, reduction in reservoirs capacity (1% to 2% annually), and loss of biodiversity. Conversion from natural to managed ecosystems, and extractive farming practices based on low external input and soil degrading land use tend to deplete the terrestrial C pools. The soil pool loses 1.1 Pg C into the atmosphere as a result of soil erosion and another 0.3-0.8 Pg C yr^{-1} to the ocean through erosion-induced transportation to aquatic ecosystems (Lal, 2011). Therefore, research and development need to focus on accurately assessing and mapping of erosion hazards, soil fertility loss, water pollution and prioritizing the erosion risk areas, for in depth assessment of the status of land degradation due to water erosion to help in planning of precision conservation measures at watershed, region and country levels.

Production losses due to soil erosion

The loss in crop productivity caused by land degradation is of great significance as it has direct impact on food security of the country. Erosion induced reduction in crop productivity may vary from <5% to >50%. IISWC has estimated that 27 major rainfed crops (cereals (8), oilseeds (10) and pulses (9)) cultivated on alluvial, black and red soils in the country as a whole suffer a production loss of 16%, which in actual physical terms works out to 13.4



million tonnes, which in economic terms is equivalent to $162 billion, considering minimum support prices of 2008-09 (Sharda *et al.,* 2010). Cereals contribute 66% to the total production loss followed by oilseeds (21%) and pulses (13%). There is now an urgency to minimize the production losses in rainfed areas of the country, as these losses can be enormous on cumulative basis to significantly affect the agrarian economy of the country over the years. To prevent further decline in productivity levels, the challenge is to:

(i) (i) Innovate and test cost-effective location-specific conservation technologies for different climatic, edaphic and physiographic conditions.

(ii) Introduce and evaluate exotic / improved germplasm.

(iii) Efficiently manage natural resources through conservation agriculture, horticulture and agroforestry, and identify potential systems for carbon sequestration under different best management practices.

Shrinking land resources

During the past five decades (1950-51 to 2004-2005), area under agriculture increased by 23 Mha from 119 Mha to 141 Mha, while uncultivated area declined by 22 Mha from 49 Mha to 27 Mha. Presently, the net sown area is 46.3%, which along with fallow land of 25 Mha accounts for 54.5% of total land use. It is estimated that per capita land availability, which was 0.32 ha in 2001 against the world average of 2.19 ha, will decrease to 0.23 ha in 2025 and 0.09 ha in 2050 (GOI, 2011). Also, over the past 60 years, area under current fallow has increased by 38% due to deterioration of land quality / soil health. Under such a scenario, productivity needs to be significantly improved by protecting existing agricultural land from degradation, and reclaiming degraded lands through appropriate conservation strategies. The research should focus upon:

(i) (i) Evolving conservation-cum-production technologies that sustain productivity of smallholders' agriculture.

(ii) Developing suitable integrated farming system (IFS) models that address production issues of smallholders such as profitability and risk, as well as supply food items to the Indian market that satisfy diverse needs of growing Indian population.

Water scarcity

It is estimated that by 2050, about 22% of the total geographic area and 17% of the population will face water scarcity. Per capita water availability, which was about 1704 m^3 in 2010, is projected to be 1235 m^3 in 2050 (GOI, 2011). This would classify the country as a water stressed region with less than 1700 m^3 water available per person (Falkenmark, 1994). Water scarcity is the outcome of the ever growing population, which results into higher demand for water in agriculture, industrial and domestic sectors. Consequently, share of agriculture sector in total water use may reduce from 78% at present to 68% in 2050 due to competing demands from other sectors. Ground water, which is the major source of irrigation at present, is rapidly declining by about 1 m annually in the rice-wheat areas due to over-exploitation. During the decade from 1994 to 2004, the percentage of over exploited blocks where ground water extraction exceeded ground water recharge, rose from 4% to 15%. Therefore, goals of enhanced food production and agricultural growth will have to be accomplished from declining availability of water, thus necessitating its efficient and optimal utilization. Research needs to focus on:

(i) (i) Harvesting more surface water as potentially about 24 million ha-m of rainwater can be harvested through small scale water harvesting structures in different rainfall zones of India, of which, about one-fourth can be harvested in zones receiving rainfall < 1000 mm/year. By this, an additional food grain production of about 60-65 million tonnes can be easily realized.

(ii) Augmenting rainwater storage as ground water to increase rainwater use efficiency.

(iii) Conserving more soil moisture through identification of suitable *in-situ* moisture conservation practices and refinement of existing ones for different production systems to make them farmer friendly, and

(iv) Producing more food with less water through ecologically sustainable cropping systems, efficient irrigation technologies and innovative cultivation methods.

Climate change hazards

Climate change has increased risk and unpredictability for farmers (especially of small and marginal categories, which are most vulnerable and least able to adapt to the changes) by warming and related aridity, and shifts in rainfall patterns and intensities resulting into growing incidence of extreme weather events. Projections of monsoon rainfall pattern over the Indian subcontinent indicate that by 2050, a 10% increase in the amount and 10% increase in the intensity of rainfall are very likely due to climate change, leading to increase in erosive power of rainfall. Based on the results of Sharda and Ojasvi (2006), it is projected that a 1% increase in rainfall intensity may increase the rainfall erosivity by 2.0%. Another study on interrill erosion by Ojasvi *et al.* (2006) indicates that 1% increase in rainfall intensity may increase soil loss from croplands by 1.5%.

By 2050, the erosion rates of water erosion class 5-10 t ha^{-1} yr^{-1} are expected to increase to more than 10 t ha^{-1} yr^{-1}, which is presently considered as the land degrading soil erosion rate. Hence, about 66 M ha area in our country under the erosion class of 5-10 t ha^{-1} yr^{-1} that covers mostly croplands will be additionally affected by higher rates of erosion due to climate induced changes in rainfall. This will result in significant increase in water erosion affected land degradation area from the current levels, unless ameliorative measures are taken. These projections also suggest that a comprehensive knowledge-base on land degradation scenario due to various driving forces in our country should also be developed and updated for the benefit of various stakeholders.

Further, temperature rise and extremes of weather would cause drastic changes in India's hydrologic cycle that would threaten water supplies for agriculture production. For controlling increased erosion due to climate change, research needs to focus on redesigning conservation structures such as bunds, trenches etc. to handle the excess runoff and soil loss. The inevitable runoff from high intensity storms over space and time would require to be harvested by redesigning water harvesting structures for providing supplemental irrigation.

Participatory integrated watershed management

People's participation is now recognized all over the world as an essential component in natural resource management. Involvement of primary stakeholders at local level and communities at higher scales and zones is considered to be imperative for addressing cross-ecosystem issues and interactions. Although many promising technologies and practices have been generated for making agriculture and natural resource management more sustainable, most of these require investment by farmers, both individually on their own farms and also collectively through groups or communities. In addition to farming communities, there are other key outside stakeholders such as the project implementing government and non-

government agencies, researchers, planners and policy makers that are critical for addressing the complex problems and challenges in multi-purpose, multi-scale, temporal and diverse watershed contexts. With so many complexities, there exists a gap between the project goals and the ground realities, making it difficult to realize the full benefits. The challenge is to integrate tangible and intangible results/outputs between stakeholders, especially those related to people's needs as they spend a great deal of time in the participatory process.

Capacity building for future

Capacity building is an integral component of the Institute's activities. The Institute conducts capacity building courses of varying durations regularly for policy makers, NGOs, field functionaries and farmers in soil and water conservation and watershed management. With its vast experience, trainings are being organized in a network mode with adequate curricula and training modules for different levels of stakeholders, employing modern tools and procedures for better understanding of the concept or technologies. The Institute also conducts specialized tailor-made short term training and sensitization courses for officers/officials sponsored by various agencies in India and abroad. For improving the outputs and outcomes of the huge public funds being invested by the governments through its various flagship schemes for rural and natural resources development, many more of these stakeholders need to be re-trained. Considering developments in ICT, there is a need to develop and use web-based information dissemination tools for effective implementation of client-based resource conservation technologies. Actions are also required to strengthen and have more collaborative land and water institutions, and provide efficient support services, including flexible knowledge exchange.

❑

Operating Environment

The economic growth of the country is highly dependent on growth in agricultural sector. Indian agriculture represents a typical case of unity in diversity and resilience even under highly vulnerable and risk prone situations. India has been divided into five major ecosystems (arid to humid) and twenty agro-ecological regions (western Himalayan cold desert to islands). It has unimodal as well as bi-modal rainfall pattern. In the country, population density has increased by about 17.54% during 2001-2011. Due to high population density, agricultural census 2011 has revealed that the number of operational holdings has increased by 6.61% during 2005-06 to 2010-11. Consequently, the average size of operational holding has declined to 1.16 ha in 2010-11 as compared to 1.23 ha in 2005-06 (GoI, 2012). Indian agriculture is predominantly characterized as farming by marginal and small farmers (84.97% in 2010-11), which operates on 44.31% of the operational holdings. Social structural behaviour has resulted into fragmentation of these tiny operational holdings into more than 4 parcels of lands located about more than 0.5 km apart from each other. This fragmentation may also be for mitigation of climate risk in agriculture and heterogeneity in productivity potential present among different parcels of the land.

India ranks first among the countries that practice rainfed agriculture, both in terms of area (86 m ha) and value of produce from it. Yield gap analysis of major rainfed crops, even under existing conditions, indicated that farmers' yields are about one-quarter to one-half of achievable yields, mainly due to aberrant rainfall at critical stages (Sharma, 2013). Further, Common Pool Resources (CPRs) such as forest (reserved forest, *civil soyam* or fringe forest), water (stream, pond, ground water, springs etc.), pastures and grazing lands along with group behaviour play an important role in sustainability of agriculture, maintenance of micro-ecosystems, security of livelihood, and having inclusive growth in the country, in general, and rural settings, in particular. The development of answers in the form of technical solutions to the challenges is thwarted by such operating environment.

1. 1. Extensive efforts for use of ICT in developing and popularizing of software for adoption of soil and water conservation technologies, basket of best management practices (BMPs), precision agriculture and conjunctive use of surface and groundwater resources in

integrated manner by use of high resolution data and socio-economic parameters.

2. Development and adoption of multi-objective decision making tools for preparation of most suitable and adaptable farming systems and/ or watershed based plans/models along with testing their validity in real field situation for adaptation to floods and management of droughts under changing climate scenarios.
3. Understand group/society/collaborative dynamics, backward and forward linkages, social equity issues and livelihood alternatives for inclusive growth.
4. Assessing the impact of climate change on soil and water resources, and quantification and valuation of tangible and intangible benefits for raising the funds for watershed development programmes.
5. Capacity development programmes for skill enhancement, better coordination and capitalize the synergistic relation among partners to bridge the gap between research findings and farmers' field realization.

❑

Opportunities

New frontiers of research tools and procedures shall be seamlessly utilized in the field of conservation and management of soil and water resources for improving productivity, enhancing input use efficiency, innovating cost-effective technological solutions, minimizing risks and improving quality of these natural resources. New mechanisms, tools, methods, techniques and approaches that promise better understanding of status and management of soil and water resources in the country for accelerating innovations in natural resources management, and providing effective institutional and policy support would be employed. All research efforts will leverage the potential of frontier sciences like Nanotechnologies, Decision Support Systems, Artificial Intelligence, Information and Communication Technology, Remote Sensing, Geographic Information System, Global Positioning System, and Process Based Models. These frontier sciences and techniques would be well integrated with on-going and future agricultural research endeavours for improving research efficiency, better targeting of technologies, and identifying production and marketing environments. Various interests of different stakeholders in natural resource management and diversification would also be addressed and realized.

There are a number of gaps and inconsistencies in existing data bases and information systems on natural resources. These gaps should be bridged by further inventories of land and water resources to help taking informed decisions and implementation. Further research on existing farming systems is essential to determine conservation opportunities and intensification strategies. Besides, numerous indigenous innovative conservation practices followed by the farmers can be converted to modern technical knowledge by addressing researchable issues (Mishra, 2002). Methods of assessing and valuing ecosystem services, including land and water assessment, should be developed to provide the tools that are needed to evaluate development options. Communication and electronic networks need to be made more effective in exchanging and disseminating knowledge, and for identifying and filling knowledge gaps.

Potential of remote sensing and GIS techniques

Use of remote sensing and GIS techniques has led to systematic inventorying of databases, characterization of erosion hazards, and use of large-scale hydrologic models, but their spatial resolution is far from satisfactory for applied uses. With the recent advancement and availability of high resolution data, their potential needs to be utilized for accurately assessing and mapping erosion hazards, soil fertility status, water resources availability, and undertaking simulation exercise through modelling. Technology for precision conservation based on watershed scale models, high resolution remote sensing and GIS for drainage line treatment, mass erosion control, and partial area treatment of watersheds should be developed for effective and economic implementation of land and water management practices. This technological enhancement and innovation will facilitate participatory resource planning.

Hydrologic models and watershed management technology

Productivity of agriculture is largely dependent on efficient management and utilization of water resources following watershed approach. However, there are issues of refining and upscaling available technologies and models from micro to macro scales across different agro-ecological regions by adding new dimensions of quality aspects and pollution related problems. Therefore, systematic efforts are required to evaluate, monitor and address the problems on a regional basis. Watershed-based simulation models (Ojasvi and Sharda, 2006) for hydrologic characterization of water sources help in long-term planning of its development and management with respect to rainfall variations (Sharda *et al.*, 2009). Potential of rainwater management and utilization through micro-irrigation and integrated farming systems, groundwater recharge, estimating runoff and soil loss on regional basis, assessment and monitoring water availability, impacts of resource conservation technologies and watershed development programmes, hydrological implications of upstream-downstream linkages of habitations, impacts of watershed development programmes on flow regimes and perenniality of streams and rivers (including drying of springs), and development of software solutions for stream bank protection structures needs to be studied further and suitably refined in different agro-ecological regions. Watershed based hydrologic models need to be perfected for proper understanding of resources dynamics and their management at different scales. Great opportunities exist for developing DSS and tools for comprehensive design and management of watersheds by integrating resource models and management information systems (MIS).

Bio-engineering measures - green technology for rehabilitation

Conservation technologies such as contour farming, tillage, mulching, vegetative barriers, crop geometry, inter cropping / mixed cropping etc. on 2-8% sloping lands have reduced runoff by 8-40% and soil loss by 6-35%. The corresponding increase in productivity was 3-28%. However, technology development process needs to be responsive to the ever changing needs of agriculture. Innovative farming practices, primarily comprising agro-forestry have tremendous scope of increasing productivity and conservation of natural resources in future through agri-silvicultural, agri-horticultural, and silvi-pastoral practices, which have been established to increase phyto-productivity from arable and non-arable lands. Conservation agriculture / horticulture technologies like organic farming, mulching, tillage, micro irrigation, fertigation and canopy management hold a great promise towards increasing productivity of all primary production systems, and they need to be evaluated in new micro-environments in different agro-climatic regions. Integrated nutrient and micro-irrigation systems need to be dovetailed with different farming practices for wider adaptability on watershed basis. Technologies related to soil erosion, alternative land use systems, diversification, biodiversity (ecological succession), vegetative barriers, bio-remediation and management of common property resources have been investigated. However, their impact on sustainable production has to be fully realized under farmer's field conditions. Use of nano-technologies in resource conservation, for sediment/pesticide filtering to improve water quality, artificial recharge filters and sealing for water storage structures is another promising area of research. All these aim at developing cost effective farmer friendly technologies.

Rainwater harvesting (RWH)

RWH aims to minimize the effects of variations in water availability and to enhance the reliability of agricultural production. RWH

covers a broad spectrum of different technologies from simple measures such as micro-catchments to more complex structures such as dams. It can serve multitude of physical to social benefits like enhancing crop productivity, food supply and income, increasing water and fodder for livestock, increasing rainfall infiltration, thus recharging shallow groundwater sources and base flow in rivers, reducing flood incidence, reducing soil erosion and sedimentation, and bridging water supply in droughts and dry spells. Functional relationships are being developed for estimating average recharge from various RWH structures in different agro-ecological regions. Based on the catchment area, ponded area and capacity, recharge can be estimated from various structures which will help in sizing the structures for a certain quantity of recharge.

Due to advances in rainwater harvesting technology, integrated rainwater harvesting is increasingly viewed as an integral part of water cycle management. Irrigation has been an integral part of our monsoon-dependent agriculture and the aggravating groundwater crisis in many States has resulted in the government adopting measures to control it. Modern techniques such as micro-irrigation, watershed management, rainwater harvesting and groundwater recharging will be vital in utilizing the existing resources and expanding irrigation in a viable manner. Integration of low cost rainwater harvesting and micro-irrigation, especially in areas having low water availability due to various reasons, such as mid Himalayan regions, has been observed to be water saving, and therefore more efficient than traditional systems. Integration of low cost poly-lined water harvesting tanks (10 m^3) with low cost drip system for irrigation of tomato crop in a pilot study undertaken in a hilly watershed of Uttarakhand resulted in 10% increase in tomato yield (42.35 t/ha) with alternate day irrigation frequency as compared to farmers practice (38.28 t/ha). The integrated system can irrigate 3.5 times more area with same amount of stored water as compared to traditional farmers' practice. In addition, the system is convenient and labour saving as compared to hand watering normally practiced in hilly regions (Source: CSWCRTI, 2012c). Such systems need to be evolved and up-scaled for sustainable production. A large potential exists to research upon multiple use of harvested water with due respect to water quality.

Rainfed agriculture – new areas of growth

Land productivity is generally low on rainfed croplands, because of low inherent soil fertility, severe nutrient depletion, poor soil structure and inappropriate soil management practices. The potential of rainfed areas needs to be tapped through sustainable land and water management techniques. Conservation agriculture, zero tillage and micro-irrigation need to be perfected for different agro-ecological regions. Efficient farming systems, composite farming, integrated crop management, integrated nutrient management, and integrated water management need to be dovetailed for wider adaptability to alleviate poverty and ensure food and environmental security in rainfed areas in the changing climate scenario. By focusing on nitrogen and carbon cycles, these practices can also enhance carbon sequestration and mitigate GHG emissions.

Carbon sequestration - carbon trading

Restored degraded lands and drastically disturbed ecosystems (i.e. mined lands) are an important sink for atmospheric CO_2. Identification of potential systems for carbon sequestration together with cost aspects under different best management practices of soil rejuvenation / soil quality requires urgent attention, especially in sloping lands. New stocks of crops and trees developed through modern genetic engineering techniques hold great promise under different agroforestry systems in the backdrop of global warming and climate change impacts. Using the median carbon sequestration potential of 1.88 metric ton per hectare per year (Dixon, 1995) and the estimate of total land area under agro-forestry (1023 m ha), Nair *et al.* (2009) estimated carbon sequestration potential of 1.9 giga ton of carbon per year by agroforestry. Loss of SOC with sediment can also be reduced resulting in carbon sequestration through resource conservation measures. Figure 2 depicts such a result with effective vegetative strips laid out in the maize field. Developing decision support tools for efficient input management would be essential along with effective bridging of information gaps (technology transfer

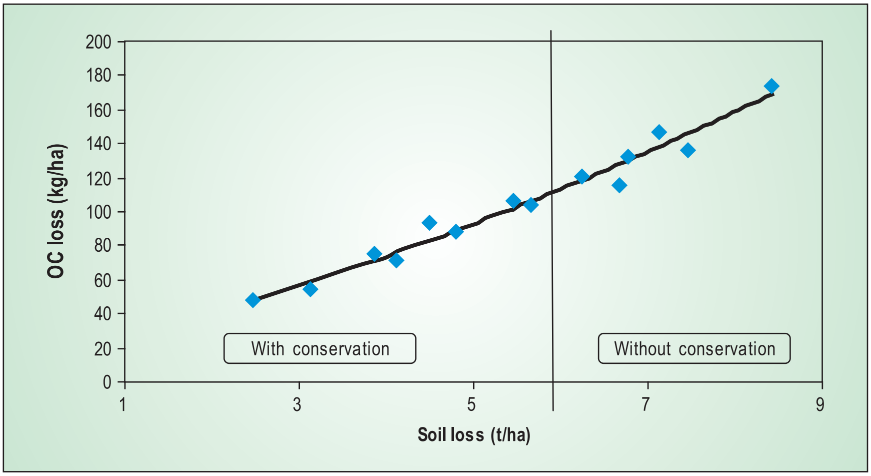


Fig. 2 Carbon sequestration potential of soil conservation practices on mild sloping land (2%) in sub-humid region. (Source: CSWCRTI, 2012a)

system) and related policy changes for effective implementation of technologies. An important and upcoming incentive for investment in soil restoration is carbon trading through clean development mechanisms, which would create another income stream for farmers. There is, however, a need to develop tools to assess C sequestration potential of resource conservation technologies.

Conservation planning for climate change

A major challenge in the coming decades will be to mitigate the impacts of climate change, which otherwise could spell catastrophe for India's agriculture and freshwater supplies. For controlling increased soil erosion due to climate change, the size of conservation structures such as bunds, trenches etc. need to be redesigned to handle the additional runoff and soil loss. The inevitable runoff received through high intensity rain storms would have to be harvested by redesigning water harvesting structures for providing supplemental irrigation. Agroforestry and horticultural technologies have great potential towards contingency planning for drought mitigation in the backdrop of global warming and climate change in the coming decades. They would have to be suitably modified for addressing this emerging problem. The climate change scenario pose a great challenge to protect the agricultural lands from land slips and landslides.

Potential of participatory integrated watershed management

The concept of watershed planning, development and management has emerged as a new paradigm for efficient management of land, water and other natural resources following bottom up participatory approaches. The success of watershed management concept in flood and drought moderation, ground water augmentation, increased biomass production, employment generation and improvement in socio-economic conditions of the local community was amply demonstrated through several model watershed projects implemented by IISWC from 1970 onward. The Institute did pioneering work in evolving and popularizing the concept of participatory integrated watershed management in the country with due emphasis on transparency, and equitable sharing of benefits and resources through community based organizations and peoples' participation. Watershed development programmes provided multiple benefits in terms of enhancing income, generating rural employment, increasing crop yields, reducing runoff and soil loss, augmenting ground water recharge, and alleviating poverty. More model watershed development projects need to be executed in different agro-ecological regions of the country for wider adoption of conservation-cum-production technologies by the state development agencies to harvest the tremendous benefits, including mitigation of negative impacts of climatic changes. There is enough scope to research upon and popularise new science tools in designing cost-effective watershed plans for effective management.

Decision support system for sustainable land management

The farming community and the government play a major role in the management of natural resources at the watershed level. The multiple objectives of watershed management comprise of a combination of technologies, policies and programmes. Watershed management essentially aims at achieving the various objectives of the multi-stakeholders, which is often restricted by their inability to take appropriate and timely decisions. Thus, there is a need for developing user-friendly decision support systems for effective resource utilization planning and validation of outputs in watershed management programmes.

Intangible benefits and ecosystem services

In planning and management context, quantification and valuation of benefits plays a pivotal role. It is used to help determine optimal management programmes. It involves comparing benefits to costs to ensure that programme elements yield a positive return, and then comparing the estimated net returns across different combinations of programme elements to find the most beneficial combination. Quantification of intangible benefits accruing from the adoption of NRM technologies would help in justifying the expensive interventions adopted in a watershed. In the present approaches, the intangible benefits are largely ignored as tools and techniques to reliably and authentically quantify and valuate them are not available. To address these complex issues, an integrated assessment of tangible and intangible benefits is essentially required by evolving suitable scientific techniques to quantify and valuate the intangible benefits by assigning appropriate weight age to the governing parameters.

Policy issues and institutional analysis

At present, appropriate attention is not being given to the issues of new trends in technology transfer and their implications on regional, national and international level policy formulations. Low level of technology adoption may result from lacunae in the government policies and laws, and poor information sharing amongst the stakeholders. It requires proper research attention so that there is an impact during the decision making process. The major focus should be to ensure that technology may be most effectively transferred from the policy planners right up to the farmers in a transparent manner, and address all the barriers that affect its transfer. Policy advocacy for mandatory adoption of natural resources conservation measures in the areas that witness soil erosion losses beyond the permissible limits will have to be initiated at state, regional and national levels. Only the percolation of policy changes at various levels of the executive can strengthen the institutional mechanisms.

Women empowerment and gender mainstreaming

Women constitute 32% of the agricultural workforce in the Indian sub-continent, and this percentage is rising due to the migration of men to urban areas. They are, however, rarely involved in decision-making related to on farm food production due to social customs, economic dependence, and low education levels. Conservation of natural resources and increased water availability has the potential of lessening the toil of everyday farm and domestic chores through their involvement in watershed management programmes. It is important to assess the extent of involvement of women in natural resources conservation, constraints restricting their participation, and recommending strategies for their increased participation. More women participation results in better outputs from watershed programmes. Further, selective mechanization will reduce the drudgery as agricultural operations, including land and crop management, are handled by women farmers.

Human resources development

A well-trained technical manpower is a pre-requisite for effective planning and execution of watershed development programmes. Well-informed farming community will adopt new technologies and strengthen the process of natural resources conservation along with increased productivity to meet the future challenges of food security. Thus, there is a strong need to build the capacity of all the stakeholders to facilitate the most efficient decision making leading to conservation of natural resources through the watershed approach. Recognizing this fact, the Government of India has kept a provision for training and capacity building to the tune of 5% of the total cost in all the centrally funded watershed development programmes. It is estimated that training needs would increase manifold in future necessitating organization of about 19000 short term training courses each year (25 persons per course) to train various categories of watershed functionaries, which include farmers/watershed committee members, members of project implementing agencies (PIAs) and watershed development teams (WDTs), district officers, state-level officers and policy planners. Hence, capacity building of stakeholders involved with NRM from grass-root workers to policy planners will constitute important activity of the Institute with emphasis on the current issues. This invariably would need concerted efforts in up-scaling the training facilities and infrastructure to provide quality training material and services. Focussed attention is required in organising more and more skill development trainings on soil & water conservation techniques.

Besides, the scientists must be trained in advance laboratories and in latest tools and techniques in and outside the country to tackle the R&D problems relating to climate change, integrated land and water management systems, resource conservation models using remote sensing and GIS, advance computing techniques, carbon sequestration and budgeting etc. This will help in reducing the communication gap in understanding all the aspects of resource conservation at par with developed nations.

❑

Goals and Targets

The Indian Institute of Soil and Water Conservation has continuously strived hard for effective development and management of the country's precious soil and water resources through frontier research and imparting technical skills to manpower engaged in the field of natural resource conservation and watershed management.

Our vision is *conservation and management of soil and water resources of the country for sustainable and enhanced production.*

The following strategies would be adopted to accomplish the vision and goal of the Indian Institute of Soil and Water Conservation and enhance the efficient utilization of natural resources for sustainable production.

Develop knowledge base and expert systems

- Analysis of hydrologic extremes and assessment of Hydrologic Foot Prints (HFP) of various BMPs to upscale watershed technologies to a larger scale.
- Use of advanced techniques such as artificial intelligence, process modelling, remote sensing, GIS and development of decision support system and expert system for watershed planning, water resources development and management, and land use planning and management for productivity enhancement.
- Develop Rainwater Harvesting Atlas of India, a GIS database on water harvesting potential in different agro-ecological regions of the country with information on engineering technologies and hydrological implications of future climate change scenarios.
- Develop Soil Erosion Database of India, a GIS database on water erosion in different agro-ecological regions of the country with information on hydrological implications of land use changes, human interferences, environmental services of erosion and future climate change scenarios.
- Upscaling and dissemination of conservation technologies through modelling applications, software and web technologies.

Precision conservation and green technology

- Identification of hot spots from point of view of soil erosion hazards and land degradation processes in different landforms like hill slopes, ravines, stream banks, torrents, rainfed uplands, and flood plains.
- Develop the concept of Apply Where Needed (AWN) for precision conservation based on watershed scale models, high resolution remote sensing and GIS for drainage line treatment, mass erosion control, and partial area treatment of watersheds.
- Understanding the energy need of various natural resources management technologies (Green technology) to assess carbon foot print of various interventions.
- Use of nano-technologies in resource conservation, for sediment/ pesticide filtering for improving water quality, artificial recharge filters and sealing for water storage structures.
- Studies on point and non-point contamination from watersheds, their dynamics and implications on water quality, reservoirs, and downstream water bodies.

Congruent planning of surface and groundwater (COP-SAG)

Based on the fact that technology will be developed to delineate both the surface and groundwater regime, integrated water resource management planning would become more effective in following ways:

- Assess water availability and upstream-downstream linkages at micro and macro watershed scales employing modern tools and procedures for effective planning of watersheds and conjunctive use of surface and groundwater.
- Characterization of hydrology of springs and other natural water sources and develop bio-engineering technology for spring sanctuaries for effective recharging and perenniality of flow.
- Augmenting groundwater recharge from surface storage structures and need based sizing through full scale hydrological monitoring with due regard to surface water quality.
- Assess rainwater storage potential in different terrain conditions and improve rain water use efficiency/ water productivity through prolonged storage and multiple water use, especially in the light of climate change impacts.

Conservation agriculture for land and water Management

- For effective farm mechanisation- suitable implements are required to be evaluated to carry out the important operations keeping in view the principle of conservation agriculture.
- Long term evaluation of conservation agriculture practices for resource conservation under rainfed conditions.
- Crop diversification by identification of suitable cropping systems which involve crops that require least disturbance to the soil for its cultivation along with more biomass production for biomass recycling.

Climate change mitigation and adaptations

- Development of appropriate cost effective user friendly rainwater harvesting, conveyance and application interventions under various rainfall scenarios.
- Development of cost effective mass erosion control measures for controlling landslides, riparian zone erosion and mine spoils keeping in view the threats from changed rainfall patterns due to climate change.
- Development of climatic resilient resource conservation techniques.
- Improving soil carbon sequestration through identification and evaluation of potential systems for carbon sequestration through best management practices, under different land uses and conservation agriculture.
- Application of different C models for assessment of carbon sequestration potential of resource conservation practices.

Assess land degradation and erosion risk for conservation planning

- Development of physical, chemical and biological indicators for assessment of land degradation and impact of conservation measures on soil health.
- Development of erosion productivity relationship under different agroclimatic zones to help modify cropping systems in relation to intensity of degradation and vulnerability.
- Strengthen collaborative research and development projects involving R&D organization in different agro-ecological regions for improved land and water management based on tested technologies.

Develop appropriate cost effective resource conservation technologies and their upscaling for better technology adoption

- Regional level Contingent Planning to mitigate drought and management for aberrant agro-climatic conditions.
- Develop conservation technologies and innovative farming practices, and test their efficacy for sustainable production under farmer's field conditions.
- Upscale existing agro-forestry systems in degraded lands by conducting multi-locational trials in different agro-ecological regions to generate location specific technologies.
- Focus on rainfed, marginal, fragile and degraded areas to check land degradation and their effective utilization.
- Develop linkages with national and international R&D organizations / developmental agencies and other stakeholders for technology development, refinement and their adoption.

Agroforestry and horticulture for resource conservation

- Development of hi-tech nurseries based on advanced techniques of bio-technology for production of quality planting materials of species having high soil conservation value in different agro-climatic zones of the country.
- Characterize new varieties of major crops, traditional crops, fruits, vegetables, spices, medicinal and aromatic plants, and elite provenances of multipurpose trees for resource conservation in different agro-climatic regions.
- Identify potential low cost systems for carbon sequestration under different best management practices for soil quality improvement.
- Identify suitable fruits, trees and grasses to address the issues of climate change impacts and sustained productivity.
- Assess efficacy of buffer strips, vegetative barriers or strips for improving the water quality parameters and check erosion in the different agro-ecological zones.
- Introduce conservation friendly "high value low volume" fruits, vegetables, spices and plantation crops in watershed for sustainable production with high economic returns in different agro-ecological regions.
- Study the below ground root biomass for tree-crop interaction and its impact on resource conservation.
- Enhance nutrient use efficiency through integrated use of organic manures and fertilizers for resource conservation and sustained productivity.

- Refine architectural management practices like canopy and root management by pruning and training in established plantations for enhancing biomass production, soil binding, nutrient cycling and water yield.

Socio-economic analysis and policy development for watershed management

- Optimal land use planning by employing multi-period and multi-objective dynamic programming techniques covering backward and forward market linkages.
- Assessment of payments for ecosystem services due to natural resource management and trade-offs.
- Develop user friendly Decision Support Systems for different situations at farm and watershed levels for planning, adoption of sustainable land management practices and their evaluation for optimizing resource utilization.
- Evolve suitable indicators/methodology for quantification of intangible benefits and environmental externalities of ecosystem payment services through multi-disciplinary approach.
- Develop policies and institutional mechanisms based on the NRM research findings and feedback from the stakeholders leading to advocacy for mandatory adoption of natural resources conservation measures.

Human resource development and technology transfer

- Capacity building of various stakeholders through establishment of Advanced Skill Development Centre- A Centre of Excellence in the Soil and Water Conservation and Watershed Management for professional training, disseminating and refining NRM technologies at the national and international level.
- Periodic up-gradation of capacity of scientists and technical officers of the Institute on new and emerging technologies related to NRM, watershed management, communication, policy formulation etc. in reputed universities and Institutions abroad.
- Develop mechanism for enhancing the impact of capacity building programmes.
- Policy research for developing effective community organization at watershed level.
- Develop standard delivery mechanisms and processes for transfer of NRM technologies.

- Documentation and scientific validation of Indigenous Technical Knowledge (ITK) in the field of NRM for converting to Modern Technical Knowledge (MTK).
- Develop policies for institutional mechanism for providing incentives to the farmers based on adoption of conservation measures.
- Develop cost-effective tools/methods for effective transfer and adoption of technology using ICT in addition to the participatory research, OFTs and FLDs to strengthen the outreach programme. Refine technology transfer methodology along with strengthening of linkages with line departments and other agencies for funding and effective technology transfer.

❑

Way Forward

The Indian Institute of Soil and Water Conservation is committed to the development of modern resource conserving technologies for effective development and management of our precious natural resources through research endeavours to achieve targeted production levels in future. Pathways to achieve stated goals is depicted in Fig. 3 and are described as follows.

- Development of technically sound, economically viable, environmentally non-degrading and socially acceptable strategies for conservation, management and efficient utilization of country's land, water, vegetation, livestock and human resources to promote sustainable growth of agriculture would be the ultimate aim of future research endeavours.

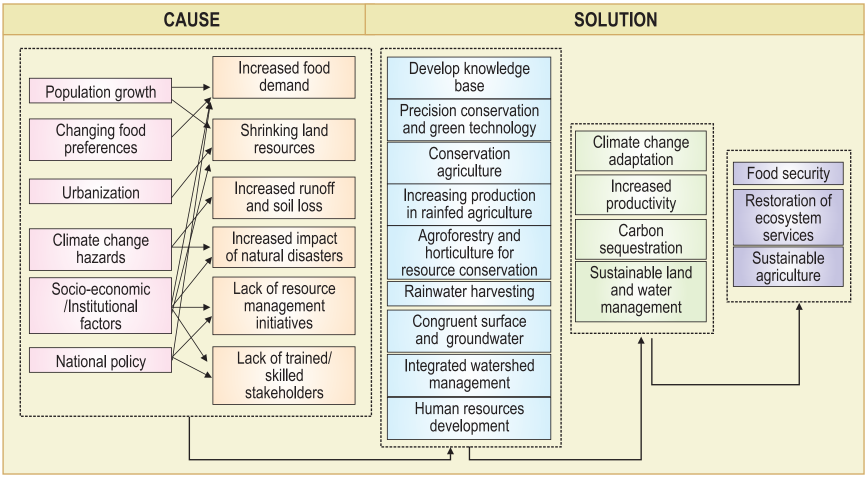


Fig. 3 Cause-solution pathways for sustainable land and water management

- By 2050, we should replace the current development process with a model of growth based on the balanced use of renewable resources and recycling those that are non-renewable.
- A new version of the Green Revolution which is knowledge-intensive, and builds the capacity of farmers to manage agricultural land for higher productivity and resource input efficiency has to be initiated. It should also entail increased biological and genetic

knowledge along with improved land and water management practices for optimum water-nutrient-energy efficiency.

- Knowledge-based inputs require more rigorous understanding and integration of biophysical and socio-economic processes involved in agricultural production, and water resources generation and management. These include climatic, hydrologic, soil-water quality, ground recharge, crop growth, and economic processes at farm, regional and global levels. Extensive field, laboratory and theoretical simulation research of high precision is required to make forecasts or predictions that can be incorporated into the resource management decision making processes. This will also require to develop new and enhancement solutions for extreme climatic conditions.
- Extensive data, information and knowledge systems at various spatial and temporal scales need to be generated and shared among wide-and-diverse networks. Improved understanding of system behaviour needs to be accompanied by effective decision making tools for various stakeholders.
- Rainwater harvesting and wastewater management will have to be adopted and improved to increase the productivity of rainfed agriculture. Conservation agriculture will be the key for providing more water for crops as soil moisture in concert with other resource efficiency enhancing agronomical practices. Restoration of degraded land for production of food, fodder, biofuel and timber will have to be promoted for increase land, water and energy efficiency measures.
- Strategies would be needed that consider social, economic, and institutional factors to reduce vulnerability and to enhance adaptation to climate related developments and scenarios in the water sector. Groundwater may play an important role in ameliorating the worst effects of climate change on water resources. However, groundwater quality has to be monitored and maintained through watershed-based rainwater harvesting measures. Development of recharge measures and prudent use of efficient methods like micro irrigation are important.
- Formulation and refinement of well tested, farmer friendly, cost-effective and location specific conservation technologies for rainfed arable and all non-arable lands based upon the precision conservation would go a long way in efficient management of our natural resources. Need specific integrated farming systems (IFS) under different farming situations for resource conservation and higher input use efficiency would provide multiple choices to agricultural entrepreneurs. Adoption of these viable IFS models will help in

meeting the diversified food demands of our affluent population; and provide higher economic returns to our marginal and small farmers.

- Disciplinary integration in research will be promoted through establishment of Advanced Skill Development Centre- A Centre of Excellence for capacity building and refinement in soil and water conservation and watershed management technologies. Besides, formal higher education and research programme on natural resource management will be initiated.
- Focus on problem solving research for effective transfer and adoption of conservation-cum-production technologies following watershed approach along with strengthening of national and international collaborations would provide the right platform and impetus for wider adoption of resource conservation based development process.

Our slogan is **"Production needs Efficient Resource Conservation"** and **"Conserve Soil – Protect Nature"**. Hence, the Institute will continue to address the research and development process for enhanced production through appropriate integrated land and water management systems in the ensuing climate change scenario.

Human resources and training requirement

IISWC deploys a multi-disciplinary team of scientists to achieve intended goals and objectives. For taking up frontier research as envisaged in this vision and imparting technical skills to manpower engaged in the field of resource conservation, watershed and environment management, the scientific and technical manpower from different disciplines like Hydrology and Engineering, Soil Science, Agronomy, Plant Sciences, Environmental Sciences, Geo-informatics and Social Sciences are required to form the multi-disciplinary team at Institute level.

Human resource development through trainings of the scientists is a continuously evolving arena and must keep pace with the changes and advancements occurring at national and global level. Therefore, Institute's scientists must be regularly trained in advance laboratories and in latest tools and techniques in and outside the country to tackle the R&D problems relating to the following cutting edge research areas:

- Decision Support Systems
- Carbon sequestration and global warming potential of resource conservation technologies
- Bio-industrial watershed development
- Advances in soil health assessment and management

- Green accounting for watershed development
- Extreme weather modelling and climate change
- Bio-economic modelling and geo-informatics
- Advanced skills on data base management, data mining and big data analysis
- Application of nuclear science and nano-technologies in resource conservation studies
- Surface and ground water interaction modelling for quantity and quality

Infrastructure Requirement

State of art laboratories for hydrology, soil and water will be required to conduct various research activities. Besides these, well equipped research farm, office, hostel and training centre facilities would be required at all the Research Centres of the Institute.

Strategic Research and Development Framework

- Development of DSS and expert systems for watershed planning, design, management and monitoring
- Develop Rainwater Harvesting Atlas of India
- Develop Soil Erosion Database of India
- Identification of hot spots for precision conservation- develop the concept of Apply Where Needed (AWN)
- Erosion productivity relationship
- Soil erosion impact on soil organic carbon dynamics under soil and water conservation practices
- Use of nano-technologies in resource conservation
- Studies on point and non-point contamination from watersheds
- Rainwater harvesting measures and recycling with micro irrigation
- Development of groundwater recharge measures with due emphasis on water quality dynamics
- Establishment of Advanced Skill Development Centre - A Centre of Excellence for soil and water conservation and watershed management and up-gradation of the Institute to Deemed University
- Strengthening national and international collaborations and convergence with national programmes
- Convergence for corporate social responsibility initiatives

❑

REFERENCES

Amarasinghe, U. A., Shah, T., Singh, O. P. 2007. *Changing consumption patterns:Implications on food and water demand in India.* International WaterManagement Institute, IWMI Research Report 119, Colombo, Sri Lanka, 43p.

CSWCRTI (Central Soil and Water Conservation Research and Training Institute). 2012a. Annual Report 2011-12 (Yield maximization and resource conservation through organic input management by B.N. Ghosh et al.), CSWCRTI, p 20-21.

CSWCRTI (Central Soil and Water Conservation Research and Training Institute). 2012c. Annual Report 2011-12 (Integration of low cost water harvesting and micro-irrigation for resource conservation by S. Patra et al.), CSWCRTI, p 61.

Dhingra, A.S., and Rama Swamy R. DTV. 2011. INDIA: Exploring Public Private Partnership in the Irrigation Sector in India – A Scoping Study. Asian Development Bank, India Resident Mission, New Delhi, India. 228p.

Dixon, R.K. 1995. Agroforestry systems: Sources and sinks of green house gases. Agroforestry Systems, 31:99-116.

Falkenmark, M. 1994. Landscape as life support pro-vider water-related limitations. In: Graham-Smith F, ed. Population: the complex reality. London (UK): The Royal Society, p 103-116.

FAO (Food and Agriculture Organization). 2011. The state of the world's land and water resources for food and agriculture(SOLAW): Managing systems at risk. Food and Agriculture Organization of the United Nations, Rome, 50p.

GOI (Government of India). 2011. State of Indian Agriculture 2011-12. Ministry of Agriculture, GOI, New Delhi, India. 294p.

GOI (Government of India). 2012. Agricultural Census 2010-11. Agricultural Census Division, Department of Agriculture and Cooperation, Ministry of Agriculture, GoI, New Delhi.

ICAR and NAAS. 2010. *Degraded and wastelands of India:Status and spatial distribution.* Indian Council of Agricultural Research, New Delhi, India, 158p.

Lal, R. 2011. Soil carbon sequestration. SOLAW Background Thematic Report - TR04B, Food and Agriculture Organization of the United Nations, Rome, 36p.

Mishra, P.K. 2002. Indigenous technical knowledge on Soil and Water Conservation in semi-arid India. (Eds. P.K. Mishra, G. Sastry, M. Osman, G.R. MaruthiSankar and N. Babjee Rao). NATP, CRIDA, Hyderabad, 151p.

NAAS (National Academy of Agricultural Sciences). 2009. State of Indian Agriculture. New Delhi:

Nair, P.K.R., V.D. Nair, B.M. Kumar, S.G. Haile. 2009. Soil carbon sequestration in tropical agroforestry systems: A feasibility appraisal. Environmental Science and Policy, 12:1099-1111.

Ojasvi, P.R., V.N. Sharda, and Om Prakash. 2006. Evaluation of interrillerodibility parameter for soil erosion estimation. Part I. Development of model using simulated rainfall data. Indian J. Soil Cons., 34(3), 178-182.

Ojasvi, P.R. and V. N. Sharda. 2006. A simulation model for assessment of water availability on catchment scale: A tool for EIA. In: [eds. P.P. Agarwal and K.K.S. Bhatia] "Environmental Considerations in Planning and Design of Power Projects", Paramount Printers, Roorkee, pp 33-46.

Sharda, V.N., and P.R. Ojasvi. 2006. Development of daily rainfall erosivity model for sub-humid climate of outer Himalayas. Indian J. Soil Cons., 34(3), 199-203.

Sharda, V.N., Pradeep Dogra and Chandra Prakash. 2010. Production and monetary losses due to water erosion in rainfed areas of India. CSWCRTI, 206p.

Sharda, V.N., P.R. Ojasvi, Pradeep Dogra, S.O. Prasher, and R. Patel. 2009. Scenario-based assessment and management of water resources in mid-Himalayan micro-watersheds with limited data availability. Hydrological Sciences J., 54(6), 1018-1034.

Sharma, B.R. 2013. Impact of climate change on water resources and potential adaptation for Indian agriculture. Ann. Agric. Res. New Series, 34(1):1-14.

Singh, R. B. 2009. Towards a food secure India and South Asia: Making hunger a history. Available online http://www.apaari.org/wp-content/uploads/2009/08/towards-a-food-secure-india makinghunger-history.pdf

WBCSD (World Business Council for Sustainable Development). 2010. Vision 2050: The new agenda for business, WBCSD, AtarRotoPresse SA, Switzerland, 80 p.

www.publications.parliament.uk/pa/ld201415/ldhansrd/text/140724-0002.htm

❑

ABBREVIATIONS

Acronyms		Description
ARYA	:	Attracting and Retaining Youth in Agriculture
ATFC	:	Agri-tech Foresight Centres
AWN	:	Apply Where Needed
BMP	:	Best Management Practice
COP-SAG	:	Congruent Planning of Surface and Groundwater
CPR	:	Common Pool Resource
CSWCRTI	:	Central Soil & Water Conservation Research & Training Institute
DARE	:	Department of Agricultural Research & Education
FAO	:	Food and Agriculture Organization
Farmer FIRST	:	Farmer's farm, Innovations, Resources, Science and Technology
FLD	:	Field Level Demonstration
GHG	:	Greenhouse Gas
GIS	:	Geographic Information System
GoI	:	Government of India
HFP	:	Hydrologic Foot Prints
ICAR	:	Indian Council of Agricultural Research
ICT	:	Information and Communications Technology
IFS	:	Integrated Farming System
IPR	:	Intellectual Property Right
ITK	:	Indigenous Technical Knowledge
MTK	:	Modern Technical Knowledge
NAAS	:	National Academy of Agricultural Sciences, India
NGO	:	Non-Governmental Organization
NRM	:	Natural Resource Management
OFT	:	On-farm Trial
PIA	:	Project Implementing Agency
R&D	:	Research & Development
READY	:	Rural Entrepreneurship and Awareness Development Yojana
RWH	:	Rainwater Harvesting
SOC	:	Soil Organic Carbon
WDT	:	Watershed Development Team

NOTES

Laser typeset and printed at M/s Royal Offset Printers, A-89/1, Naraina Industrial Area, Phase-I, New Delhi 110 028.