# Souvenir

## National Seminar on Agrophysics for Smart Agriculture

**NASC Complex, New Delhi**

**22-23 February 2022**

SUPPORTED BY

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Organized by

Indian Society of Agrophysics

and

Division of Agricultural Physics

ICAR-IARI, New Delhi-110012

# Souvenir

**National Seminar**
**on**
**Agrophysics for Smart Agriculture**
NASC Complex, New Delhi

22-23 February 2022

INDIAN SOCIETY OF AGROPHYSICS (REGD)
IARI NEW DELHI- 1985

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**Organized by**
**The Indian Society of AgroPhysics**
**and**
**Division of Agricultural Physics**
**ICAR-IARI, New Delhi -110012**

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*Secretary*
The Indian Society of AgroPhysics
Division of Agricultural Physics
Indian Agricultural Research Institute
New Delhi - 110012

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**NARENDRA SINGH TOMAR**

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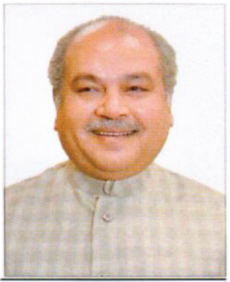
आज़ादी का अमृत महोत्सव

कृषि एवं किसान कल्याण मंत्री
भारत सरकार
कृषि भवन, नई दिल्ली

**MINISTER OF AGRICULTURE & FARMERS WELFARE**
**GOVERNMENT OF INDIA**
**KRISHI BHAWAN, NEW DELHI**



## MESSAGE

I am happy that the National Seminar on 'Agrophysics for Smart Agriculture' will have a special focus on the use of agrophysical technologies for smart agriculture. The breeding of crop varieties helps us to enhance the yield potential of crops, however, agrophysics can help us to unleash the untapped potential. We should give concurrent attention to use of modern technologies for management of natural resources. I hope the Seminar will show the way to achieve Goal no. 2 of the UN Sustainable Development Goals viz., "end hunger, achieve food security and improved nutrition and promote sustainable agriculture".

My best wishes to the organizers and participants on this occasion.

**(Narendra Singh Tomar)**

कैलाश चौधरी
**KAILASH CHOUDHARY**

सत्यमेव जयते

कृषि एवं किसान कल्याण
राज्य मंत्री
भारत सरकार
**MINISTER OF STATE FOR AGRICULTURE**
**& FARMERS WELFARE**
**GOVERNMENT OF INDIA**

# MESSAGE

It is a pleasure to know that the Indian Society of Agrophysics and the Indian Council of Agricultural Research are jointly organizing the National Seminar during 22–23 February, 2022 at New Delhi, India.

Green Revolution successfully bridged the yawning gap between supply and demand of food grains and requirements of the growing population to a large extent. However, accelerated use of natural resources, high external inputs, intensive cropping patterns and monoculture practices have contributed towards numerous food and environmental security problems. In this context, use of agrophysics techniques like drone, remote sensing, simulation modelling, AI, machine learning etc. for developing smart agriculture is indeed an apt subject and relevant in the present context. It is expected that the participants of the Seminar drawn from different spheres of agricultural science will share their expertise and experience towards widening the horizons of knowledge in the proposed area. I do hope that the deliberations of the Seminar will help for formulation of strategies to mitigate the problems for sustainable agriculture towards smart agriculture.

I wish the Seminar a grand success.

**(Kailash Choudhary)**

सत्यमेव जयते
त्रिलोचन महापात्र, पीएच.डी.
सचिव, एवं महानिदेशक
TRILOCHAN MOHAPATRA, Ph.D.
SECRETARY & DIRECTOR GENERAL

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अनुसंधान परिषद
कृषि एवं किसान कल्याण मंत्रालय, कृषि भवन, नई दिल्ली 110 001
GOVERNMENT OF INDIA
DEPARTMENT OF AGRICULTURAL RESEARCH & EDUCATION
AND
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
MINISTRY OF AGRICULTURE AND FARMERS WELFARE
KRISHI BHAVAN, NEW DELHI 110 001
Tel.: 23382629; 23386711 Fax: 91-11-23384773
E-mail: dg.icar@nic.in

## MESSAGE

I am happy to know that the Indian Society of Agrophysics and the Indian Council of Agricultural Research are organizing the National Seminar on "Agrophysics for Smart Agriculture" at New Delhi from 22–23 February, 2022. The Agricultural Physicists have played a pivotal role in developing appropriate technologies in different agro-climatic conditions for increasing productivity. I hope that the delegates attending this Seminar will discuss and interact on issues related to the use of simulation modeling, biophysical techniques, remote sensing, drone technology, machine learning and Artificial Intelligence (AI) for sustainable use of natural resources and also to come out with viable research and management strategies for providing food and nutritional security and employment to the masses.

I wish the Seminar all success.

**( T. MOHAPATRA )**

**Dated the 21st February, 2022**
**New Delhi**

भारतीय कृषि अनुसंधान परिषद
कक्ष क्र. 101, कृषि अनुसंधान भवन-II, नई दिल्ली-110 012, भारत
**INDIAN COUNCIL OF AGRICULTURAL RESEARCH**
Room No. 101, Krishi Anusandhan Bhavan-II, Pusa, New Delhi-110012, India

**डॉ. सुरेश कुमार चौधरी**
उप महानिदेशक (प्राकृतिक संसाधन प्रबंधन)
**Dr. Suresh Kumar Chaudhari**
Deputy Director General (Natural Resources Management)
&
**President, Indian Society of Agro-Physics**

**Dated: 15.02. 2022**

## Message

I am indeed happy to know that the National Seminar on "Agrophysics for Smart Agriculture" is being organized at New Delhi.

I am closely watching the strident progress made in the Indian agriculture since independence. The advent of seeds and subsequent green revolution would not have been that spectacular without matching agrophysical practices under different agro-environments developed over the years by the dedicated Agriculture Scientists. However, due to the present-day intensive agriculture demands more cautious and pragmatic approaches are required to ensure environmental safety and sustainable food production. Multi-pronged approaches involving various components of modern-day agriculture need to be evolved to tackle second generation problems of soils, water and environment.

I firmly believe that the Indian agriculture has the strength and resilience to overcome such daunting challenges with the help of strong and dedicated agricultural researchers. In this regard, the theme of the Seminar "Agrophysics for Smart Agriculture" is apt and timely. The discussions and deliberations during the Seminar, I hope, would be highly useful and lead to solving the problems associated with agriculture, livelihood and global environmental security.

I wish the Seminar a grand success.

**(S.K. Chaudhari)**

भारतीय कृषि अनुसंधान परिषद
कृषि अनुसंधान भवन–1, पूसा, नई दिल्ली 110 012
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
Krishi Anusandhan Bhawan, Pusa, New Delhi – 110 012
91-11-25843277 (O), Fax : 91-11-25842968
E-mail: aksicar@gmail.com

डा. अशोक कुमार सिंह
उप महानिदेशक (कृषि प्रसार)
Dr. A.K. Singh
Deputy Director General (Agricultural Extension)

**MESSAGE**

I am happy to know that the Indian Society of Agrophysics and the Indian Council of Agricultural Research are organizing the National Seminar on Agrophysics for Smart Agriculture during 22–23 February, 2022. Impressive achievements have been made world over in judicious use of natural resources management and enhancing agricultural production. However, the burgeoning demographic pressures, have posed a formidable challenge to the policy makers, scientists and all implementing agencies for providing livelihood to teeming millions.

Modern day agriculture faces various challenges due to degradation of natural resources and decline in factor productivity in the face of changing climate. The Agrophysicists have played a pivotal role in developing appropriate technologies for different agro-climatic conditions. There is a need for disseminating these technologies among the farming community in collaboration with extension scientists for wide adaptation and realization of their true potential. I hope that the delegates attending this Seminar will discuss and interact on issues related to smart agriculture, climate change and management of all our resources to come out with viable research and development strategies for providing food and nutritional security and also employment to the masses.

I wish the Seminar all success in its endeavours.

Dated : 15.02.2022

**(A.K. Singh)**

भारतीय कृषि अनुसंधान परिषद
कृषि एवं किसान कल्याण मंत्रालय
भारत सरकार, कृषि भवन
नई दिल्ली 110001, भारत

Indian Council of Agricultural Research
Ministry of Agriculture and Farmers Welfare
Govt. of India, Krishi Bhavan
New Delhi 110001, India

डॉ. तिलक राज शर्मा
उप महानिदेशक (फसल विज्ञान)

Dr. T. R. Sharma, Ph.D
FNA, FNAAS, FNASc, JC Bose National Fellow
Deputy Director General (Crop Science)

## MESSAGE

It is indeed a matter of great pleasure to learn that the National Seminar on "Agrophysics for Smart Agriculture" being organized from February 22–23, 2022 at New Delhi. The central theme of the Seminar "Agrophysics for Smart Agriculture" is indeed appropriate and timely. With the population of the world continuing to grow, there are major challenges to be faced in increasing the production of various agricultural crops with emphasis on ecological sustainability. Scientific developments are the foundation for promoting sustainable development in agriculture to secure food and environment for the future generations.

I congratulate the organizers; the Indian Society of Agrophysics and the Indian Council of Agricultural Research for taking the initiative to organize this Seminar at New Delhi. I am sure that the deliberations of the Seminar would benefit the scientific community in devising programmes for smart agriculture with the focus on food production and environmental security.

I wish the Seminar a grand success.

**(T.R. Sharma)**

Place : New Delhi
Dated: 15.2.22

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CELEBRATING
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कृषि अनुसंधान भवन-II, नई दिल्ली-110012
**INDIAN COUNCIL OF AGRICULTURAL RESEARCH**
KRISHI ANUSANDHAN BHAVAN-II, PUSA, NEW DELHI-110012

Phone : +91-11-25841760; Fax: +91-11-25843932
Email: ddgedu.icar@gov.in, ddgedn@gmail.com

**डा. राकेश चन्द्र अग्रवाल**
उप महानिदेशक (कृषि शिक्षा) (अ.प्र.)
**Dr. Rakesh Chandra Agrawal**
Deputy Director General (Agril. Edn.) (Act.)

## MESSAGE

I am happy to know that the Indian Society of Agrophysics and the Indian Council of Agricultural Research are organizing the National Seminar on Agrophysics for Smart Agriculture during 22–23 February, 2022. Impressive achievements have been made world over in cautious use of natural resources management and enhancing agricultural production. However, the burgeoning demographic pressures, have posed a formidable challenge to the policy makers, scientists and all other stake holders including implementing agencies for providing livelihood to teeming millions.

The agricultural production system is a highly complex subject which encompasses various disciplines of agricultural sciences. The Agrophysicists have played a pivotal role in addressing the complex soil-plant-atmosphere continuum and developing appropriate technologies for different agro-climatic conditions. I hope that the delegates attending this Seminar will discuss and interact on issues related to smart agriculture, climate change and management of the resources to come out with viable research and development of resource efficient strategies for providing food and nutritional security, also employment to the masses and doubling farmers' income.

I wish the Seminar all success in its endeavours.

(R.C. Agrawal)

भा.कृ.अ.प. – भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली–110012 (भारत)
**ICAR - INDIAN AGRICULTURAL RESEARCH INSTITUTE**
**( A DEEMED TO BE UNIVERSITY UNDER SECTION 3 OF UGC ACT, 1956)**
NEW DELHI - 110012 (INDIA)

**डॉ. अशोक कुमार सिंह**
**निदेशक**
**Dr. Ashok Kumar Singh**
**Director**

**Phones : 011-2584 2367, 2584 3375**
**Fax : 011-2584 6420**
**E-mail : director@iari.res.in**
**Personal : aks_gene@yahoo.com**
**Website : www.iari.res.in**

## MESSAGE

I am indeed happy to learn that the Indian Society of Agrophysics and the Indian Council of Agricultural Research have taken the initiative to organize the National Seminar on "Agrophysics for Smart Agriculture" from February 22–23, 2022 at New Delhi. I have been closely watching the strident Agrophysics research made in the Indian agriculture. The advent of wonder seeds and subsequent green revolution would not have been that spectacular without matching agrophysics research under different agro-environments developed over the years by the dedicated Agronomists. However, the present day intensive agriculture demands more cautious and pragmatic approach in order to ensure environmental safety and sustainable food production. Multi-pronged approaches involving various components of modern day agriculture need to be evolved to tackle second generation problems of soils, water and environment. I firmly believe that the Indian agriculture has the strength and resilience to overcome such daunting challenges with the help of strong and dedicated agricultural scientists. I congratulate the organizers for choosing a most appropriate theme of the Seminar. I am sure that the discussions and deliberations during the Seminar would be of great benefit to the scientific community in resolving the problems associated with agriculture, livelihood and smart agriculture.

I wish the Seminar a grand success.

15/2/2022
(A.K. Singh)

National Seminar on Agrophysics for Smart Agriculture
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# Paradigms of Future Agricultural Physics Research

**S.K. Chaudhari[1]* and Pragati Pramanik Maity[2]**

[1]*Division of Natural Resource Management, Indian Council of Agricultural Research, Krishi Anusandhan Bhawan-II, New Delhi-110012*

[2]*Division of Agricultural Physics, ICAR- Indian Agriculture Research Institute, New Delhi-110012*
*Email: ddg.nrm@icar.gov.in*

## Introduction

Food is the basic necessity of civilisation. Its survival demands food security, pivotal for development and in policy making. With the population increase and change in climatic conditions, bridging the gaps of global demand and supply of food grains has been the prime agenda in the past and shall continue to be in future for progress of civilisation. Agriculture as science and as practice will continue to be focussed area for developing as well as developed nation. The contribution of the scientists in understanding the science associated with the production, extension and marketing & preserving of agricultural products willmake a pathway for a paradigm shift in the conventional practices in field. This will not only enrich the scientific mind of the researchers but also help in economic boosting of the farmers.

Considering the complexity associated with the subject, integration of the knowledge of various disciplines of science and technology is the need of hour. Unprecedented advancement in information technology and its use in overall agricultural management have opened new vistas for the researchers to understand and support various decisions. Agricultural Physics which literally combines the knowledge of classical Physics which deals with mass and energy and the knowledge of biology has come a long way since its introduction in the field of agriculture. The demand for increase in production efficiency associated with climate change conditions and large-scale mechanisation in the field of agriculture are the driving force for the scientific community to usher into the minute details of the physical and biological process with the use of cut-edge technologies /tools. In future, the field of Agriculture Physics will accommodate the ignited minds of various other disciplines like chemistry, biology, engineering, information technology etc, to benefit to the society at large.

## Soil-Plant-Atmosphere Relations

Soil-plant-atmosphere relations is the near-surface environment in which mass (water, nutrients, air) and energy (heat, light) transfer occurs from soil through plants to the atmosphere (Slawiñski and Sobczuk, 2011). The system is composed of three main elements: solid soil constituents, water and air which are dynamic in time and variable in space. Soil plays the main role because it affects directly the availability of water and nutrients to plants. Plants in turn play the role of water transmission from s**oil to the atmosphere.** The processes of mass and energy transfer which proceed within the soil-plant-atmosphere system are described with physical equations and modelling in different scales like leaf scale, canopy scale, landscape scale and mesoscale.

## Agricultural Physics

It takes nature thousands of years to create life-giving soil out of sterile bedrock. It takes but a few decades for unknowing or uncaring humans to destroy that wondrous work of nature. It is for us who do care for future generations to treat the soil with respect and humility, another word derived from humus (Daniel Hillel, 1998).

Agricultural Physics, in general, is considered as a science that studies physical processes and properties affecting plant production. Physics and Biological science are integral part of it besides environment. The subject deals with the processes in lands in agricultural use, being under intensive human intervention, e.g., Monoculture crops, water management and high level of chemical and mechanical treatments. It comprises physical processes and properties of soil, plants, agricultural products and food, measuring methods, modeling and monitoring (Glinski *et al.*, 2013).

Sustainable crop production and mutual existence of various elements of nature is the key for survival. Agricultural Physicists or Agro-Physics specialists have an important role to play in either leading or helping other biologists in their efforts to identify the physical forces and their limits of tolerance by the crop, animal, insect, fish and microbial genotypes on land, in atmosphere and aquatic systems for consequences and economic yields so as to be able to feed vast human and animal populations with reasonable nutritional standard (Moharir, 2009).

Physical forces at a particular geographic location and environment dominantly control development, growth, biochemistry, physiology, movements and yields despite the best genetic makeup of a crop plant and its yield potential. And these forces also include geomagnetic field of the earth at a particular location, its intensity and modification with lunar phases and influx of normal solar radiation and occasionally abnormal coronal mass ejections from the Sun (Moharir, 2009).

## Agricultural Physics as Discipline

A cell 'Physics in Agriculture' was created in 1948 within the Division of Agricultural Chemistry in the Indian Agricultural Research Institute, New Delhi. In 1962, the cell was elevated into a full-fledged research and teaching division. Basic Concepts of Physics, Soil physics, Biophysics and Meteorology are covered under the various courses offered to the students of this discipline. With time, remote sensing and its applications in soil, water, environment and natural resource management has also become a major activity in the division. The whole curriculum has been evolved to enable students to develop and inculcate the capacity to comprehend any object of their scientific investigation / exploration from a multidisciplinary angle in a holistic way and progress into what was known in earlier centuries as 'Naturalist' and in the terminology of the twenty first century as an 'Integrative Biologist' (Moharir, 2013).

## Achievements

A National Symposium on 'Four Decades of Agricultural Physics' in India was specially organized in April 2003 to take stock of the work done in the area since inception in 1962 and to identify new avenues for further research and applications.The publication titled '*Four Decades of Research in Agricultural Physics (1962-2002) by the Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi, India, 2003, Editor A.V. Moharir, et.al.*' encapsulates the achievements of the students and scientists of this discipline.

In the context of present scenario of global atmospheric warming; changes in weather and weather patterns; pollution; rapid loss of forest and agricultural crop diversity in fields; crop growth duration, rotations and adjustments; extinction of our most precious fish, bird, insect, animal and microbiological species; identification, characterization and structure determination of bio-molecules and issues regarding intellectual property rights, there are several grounds to break and new dimensions to add (Moharir, 2009).

The subject has been acknowledged by the scientific community and many a contributions have changed the conventional agriculture practices to a certain extent. Still the subject offers immense opportunity for scientific insights which inter-alia will benefit to the society (Glinski *et al.*, 2013).

## Way Forward and Opportunities for Researchers

(i) Capture the dynamics of soil structure effects and improve quantitative description of surface roughness, crusting, bypass flow, infiltration, deformation resistance (mechanical impedance, crop establishment).

(ii) Estimation of the effective soil physical properties of heterogeneous field soil profiles. Integration of directly measured data and indirectly estimated information derived from new non-invasive techniques such as neutron and X-ray radiography, magnetic resonance imaging, electrical resistivity tomography, ground penetrating radar. Microwave remote sensing is promising for this.

(iii) Quantification of the size, continuity, orientation and irregularity of pores by means of image analysis for a broad range of agrophysical applications including water movement and solute transport following human activity.

(iv) Visualising and quantifying the complex geometry of the pore network and soil structure in 3D on various scales is promising to enhance our understanding of the multiple interacting soil physical, biological and biogeochemical processes, including flux phenomena.

(v) Quantification of coupled soil heat and water transfer (particularly vapour flow components) and associated implications at various scales.

(vi) Studying the combined effects of multiple stresses such as water stress, oxygen stress, mechanical stress, salinity, and temperature extremes on plant performance.

(vii) Further research is needed to explain perception of soil physical stress by plants (or plant roots) and the conversion of physical phenomena into physiological responses.

(viii) Development of emerging area of 3-D soil-plant functional interactions modelling based on root architecture which allows better understanding of the complex mechanisms controlling water and nutrients fluxes in the soil-plant continuum and increase root uptake efficiency. Advances made in non-invasive measurement techniques can be useful for this.

(ix) Development of complete and reliable databases of agrophysical data is challenging. They are an invaluable resource for researches, educators, practitioners and policy makers and present great opportunities to translate the existing data to the data we need using cost-effective pedotransfer functions (or model approaches).

(x) Coupling of soil mechanical and conductive (hydraulic) processes affecting the time dependent strain and the alteration of pore functioning: e.g. aeration and water fluxes to help the specification of appropriate agricultural machinery to avoid excessive soil and subsoil compaction.

(xi) Developing non-invasive soil sensors to alleviate the difficulty in researching below-ground processes (e.g. root development, water movement etc.).

(xii) More research is needed in plant breeding to develop crop varieties for physically stressed environment, e.g. lodging.

(xiii) Studies on the co-acting effects of increasing temperature and associated changes in soil moisture and rising atmospheric $CO_2$ on SOM and plant productivity, due to future climatic change.

(xiv) Management of landscape structure to optimize the use of solar energy, heat and water balance of agricultural areas towards increasing potential for sustainable production of biomass.

(xv) Creation of optimal physical conditions to increase the utility (technological) value during processing and storage.

(xvi) Improvement of technology of harvesting, storing and processing to decrease qualitative and quantitative losses using new physical methods and modelling approaches.

(xvii) Deepening of knowledge on physical properties through description of macroscopic and microscopic structures and processes.

(xviii) Saving energy during various technological processes used in agriculture.

(xix) Designing machines and devices (equipped with electronics) used in agriculture that will be economical in terms of their power (energy) and material requirements.

## Conclusions

Researchers of various disciplines has nurtured the aspirations of the society in past and will continue to be the guiding force for policy formulation and its implementation in the development process. With the advent of new technologies and various cutting age tools the time frame for the research has reduced to a larger extent and the knowledge dissemination made possible in a click. This has given the learners a great opportunity to coordinate with the experts of related fields and venture into the new challenges to implement the understanding of the physical phenomenon and thereby reaping the best out of the given situation in terms of investigation, modeling, monitoring the system so that the basic need of the civilization can be managed with environmental sustainability and economic viability.

Agricultural Physics has contributed a lot in advancement of the measurement technique thereby helping in understanding the temporal and spatial variations of physical conditions in agriculture and need monitoring (Skierucha, 2011). The contribution of the subject in every field of agriculture has been recognized thereby it has expanded its scope in product management along with production management. Challenges are many thus opportunities for ignited curious minds.

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# Towards Climate-Smart Agriculture

**H. Pathak**

*ICAR-National Institute of Abiotic Stress Management, Baramati, Maharashtra*
*Email: hpathak.iari@gmail.com*

**ABSTRACT**

The debate on whether the climate is changing or not, has been settled. It is changing and for real with substantial negative impacts. The Inter-Governmental Panel on Climate Change (IPCC) in its 6$^{th}$ Assessment Report released on August 9, 2021 observed that climate change is widespread, rapid and intensifying. The concerns currently getting raised are what the magnitude of such impacts could be, in which location and how to deal with them. The concerns are very pertinent as climate is the most important determinant of agricultural productivity globally and India, in particular. If climate goes wrong, Indian agriculture and in turn its economy cannot go right. About 50% of the total workforce is engaged in agricultural and allied activities accounting for 17% share in India's gross domestic product (GDP). Indian farming, though one of the oldest systems; is diverse, heterogeneous, unorganized and probably the riskiest with more than 50% area is rainfed and exposed to multiple biotic and abiotic stresses. Changing climate will make agriculture, which is already vulnerable, more risky and unsustainable.

## Introduction

Indian agriculture with the net sown area of about 140 million ha (M ha) has made tremendous progress over the years. India was a food scarce country till 1950, transformed itself into a food shortage (1950-1970) to food sufficient (1970-2010) to a food surplus (2010 onwards) country. It has witnessed various agri-revolutions including Green (crop), White (milk), Blue (fish), Yellow (oil), Golden (honey & horticulture), Silver (egg), Brown (coffee) and Grey (wool) Revolutions. Food grain production in the current year (2020-21) has touched an all-time high of about 305 million tonnes (Mt). New records have been achieved in the production of all crops including rice, wheat, nutri/course cereals, maize and pulses. India also harvested the most outstanding production of horticultural crops, livestock, fisheries and aquaculture. Productions of various commodities in 2020-21 have increased by 6-50 times compared to those of 1950-51 whereas area under cultivation has increased only 1.3 times during the period. Indian agriculture not only made the country self-sufficient in food but also enabled to export commodities worth 1.30 lakh crores during 2018-19 (MoAFW, 2020). Moreover, production variability of Indian agriculture has reduced, though climatic variability increased over the years. In COVID-19 pandemic situation also, agriculture sector performed well, probably the best among all the sectors of the economy. There are also indications that the greenhouse gas (GHG) emission intensity is reducing and fertilizer, particularly nitrogen use efficiency is no more decreasing, instead it has flattened and improving in recent years (Pathak *et al.*, 2019).

## Challenges in Indian Agriculture

Along with these accomplishments, newer challenges have cropped up to the forefront in recent years. Population is expected to rise to more than 1.6 billion by 2050 before approaching stabilization, food demand is likely to rise to 400 Mt. Accordingly, an agricultural growth rate of 4% per annum is needed, not only to meet the increasing demand of food, feed and fodder but also to achieve 8-9% GDP growth to reduce poverty and boost the economic growth. Although agricultural production is increasing, yet the economic contribution of agriculture to India's GDP has been declining steadily from 57% in the 1950s to about 17% in 2018-19. In addition, despite the progress made by India towards achieving the various Sustainable Development Goals (SDGs), significant gaps remain to overcome poverty, hunger and malnutrition. The ever-growing population and income have raised the demand for food but the resource base (soil, water, air) that was responsible for increasing the production has been shrinking. Profitability has been adversely affected by increasing cost of cultivation. Agriculture is therefore, no longer remains an attractive choice. A recent study shows that more than 60% farmers are more than 50 years of age and about 40% of the farmers want to leave agriculture, provided an alternative occupation is available. Moreover, the productivity growth rate for many crops has become stagnant. Indian agriculture is unsustainable due to low and volatile wages, degraded natural resource base, rising labor and energy shortages and the threats of climate change. Poor and small-holder farmers, constituting more than 85% of Indian farmers are most vulnerable to these changes. Indian agriculture, therefore, faces twin challenges of increasing productivity and profitability on one hand and making it climate-resilient on the other.

## Vulnerability of Indian Agriculture to Climate Change

India is considered to be one of the most vulnerable regions to witness climatic changes at a large scale. Atmospheric temperature, which has already risen by about 1$^{o}$C, is rising consistently. Recent observations show that minimum temperature is rising more than maximum temperature; temperature rise is more in northern than in southern parts of the country and it is becoming more variable during *rabi* than *kharif* season. The amount, intensity, variability and extreme events of rainfall (unseasonal rain, drought and flood) are rising while the duration of rainfall is reducing (IPCC, 2019). Though the impacts of climate change will vary from place to place, it is projected that yield of major crops would decline by 3-18% by 2040 under representative concentration pathway (RCP) 4.5 scenario (Naresh Kumar *et al.*, 2020). Area for suitability of growing rainfed rice to decline by 15-40%; coconut plantations to gain in western coast but loose in the eastern region; apple belt to shift to higher elevations (1250 to 2500 msl); Assam tea and Arabica coffee to lose yield; protein content in wheat to reduce by 1% and Zn and Fe content to reduce in many food grains. Milk production from livestock may decline by 15 Mt in 2050 and quality of milk also to reduce. The cross breeds, however will be affected more than the indigenous breeds. Poultry to face heat stress causing a reduction in meat and egg yield. There could be changes in sea surface temperature, precipitation, sea-water acidification, sea surface salinity and oxygen deficiency affecting the growth of zoo- and phyto-plankton and fisheries production negatively. Altered abundance, distribution, breeding and migration of marine fish species are also projected.

## Positive Effects of Climate Change

In-spite of all the adverse effects, there could be some positive impacts of climate change. Increased $CO_2$ level will have beneficial effects on the yield of crops. More rain, particularly in water-deficit areas and increased temperature in cool, temperate regions may have congenial temperature for crop growth and reduce cold injury. Increased breeding cycles and higher growth rates may also benefit freshwater fishes. The net impacts of climate change on Indian agriculture, however will be negative. With medium-term (2010-2039) climate change is predicted to reduce yields by 4.5 to 9.0%, depending on the magnitude and distribution of warming. Since agriculture accounts for approximately 16% of India's GDP, an adverse production effect of 4.5-9.9% means the cost of climate change is about 1.5% of GDP per year (Naresh Kumar *et al.*, 2020).

## Climate Smart Agriculture in India- a Noble Option

To address the emerging challenges and harness a few benefits of climate change, Indian agriculture needs to be climate smart. Climate smart agriculture (CSA) is defined as 'an integrated approach for developing technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change' (FAO, 2013). There are three pillars of CSA, namely, (i) sustainably increasing agricultural productivity and incomes, (ii) adapting and building resilience to climate change and (iii) reducing and/or removing carbon emissions. The CSA aims to improve food security, helps communities to adapt climate change and contributes to climate change mitigation by adopting appropriate practices, developing policies and mobilizing needed finances (FAO, 2013). The key dimensions of CSA refer to the system, which is water smart, weather smart, nutrient smart, energy smart, carbon smart and also knowledge smart (Bhattacharya *et al.*, 2020).

## Climate Smart Crop Improvement Program

To address the emerging climatic risks on Indian agriculture several adaptation and mitigation technologies have been developed. For field and horticultural crops developing varieties tolerant to multiple abiotic and biotic stresses using stress-tolerant QTLs, genes and alleles in elite cultivars is efficient way of achieving climate resilience with easy access to farmers. Crop varieties such as CR Dhan 801 and CR Dhan 802 for rice, and HD 3068 and HD 3226 for wheat and several for other crops, which are tolerant to multiple stresses *i.e.*, submergence, salinity, drought, heat and pest and diseases have been developed (Maheswari *et al.*, 2019). The strategy of inter-specific grafting of crops has been successful for flood-tolerance in tomato where grafting of tomato plants (cv. Arka Rakshak) were done onto brinjal rootstocks (Arka Neelkanth, Mattu Gulla and Arka Keshav). Grafted tomato plants exhibited better survival and improved fruit yield over the self-grafted and un-grafted plants under flooding (Anant *et al.*, 2015). Crop diversification focusing on promoting climate-smart, hardy crops such as millets; and more remunerative fruit crops such as dragon fruit and pomegranate in drought prone areas could be another strategy for climate resilience. New crop such as dragon fruit has got high potential to increase farmers' income, particularly in climatic stressed areas (Nangare *et al.*, 2020).

## Climate Smart Water and Nutrient Management

In the water-front, India has made significant progress in conserving, storing and enhancing water use efficiency. Pressurized, low cost and demand-driven micro-irrigation methods are promoted with substantial success. Rice is the most water-demanding crop. Technologies such as alternate wetting and drying and dry direct-seeding can reduce water consumption in rice and mitigate methane emission (Pathak *et al.*, 2015). Efficient management of nutrients can help in increasing resilience of the production system by limiting the adverse effects of the extreme weather events such as flood and drought. Nutrient efficient varieties, soil test-based fertiliser application, customized fertilizers, enhanced efficient N fertilisers, site-specific nutrient management, real time N application, integrated nutrient management are some examples of nutrient-smart practices. Use of neem-coated urea, soil health card and leaf colour chart for enhancing fertilizer use efficiency have been successfully utilized in India (Pathak *et al.*, 2016). In the changing climate scenario, microbe-based technologies for nitrogen fixation, nutrient recycling, bio-residue management and alleviation of abiotic and biotic stress will be very useful (Mohanty *et al*., 2020). Another development is conservation agriculture to reduce the carbon foot-print of the production system, improves productivity and enhances adaptability by modulating soil mositure and temperature regimes (Somasundaram *et al*., 2020). Such practices are followed by farmers in large scale in western Indo-Gangetic Plain. However, refinemnent and promotion with incentives are required to entend the technology in climatic stressed, dryland areas. Mechanization in agriculture with renewable energy sources such as solar-powered machineries such as water pumps, sprayers and weeders are better alternatives to diesel-powered machines in India. Such machines are economical, eco-friendly i.e., do not release GHGs and other polluting gases (Kumari *et al*., 2019). Information and communication technologies (ICTs) for short-term weather forecast and advisories at block level; use of mobile agromet advisory system (mAAS), rural mobile phone based (Rnet) social networking, micro-blogs, awareness programs through gosthi, chaupal gapshap; installation of rain gauge at village level and rainfall visualizer at local level could greatly help in addressing climatic extremes and develop contingency plans. Sustainable insurance system need to be developed, while the rural poor need to be informed about taking advantage of these opportunities.

## Climate Smart Livestock Management

To ensure climate resilient livestock production, stress tolerant breeds, heat stress resilient housing, providing enough good quality feed with supplements such as vitamin C for poultry (Khan *et al*., 2012), improving feeding strategy and extending financial and risk mitigation services will be of beneficial. For fisheries, composite and drought-escaping fish culture could be very useful. Amur carp (modified variety of common carp) is considered to have more growth and climate resistance compared to common carp (Medhi *et al*., 2018). In drought-escaping fish culture, fishes are grown in smaller ponds that retain water for 2-4 months and fish species such as *Pangasius* sp., *Puntius javanicus*, *Pygocentrus mattereri* and *Oreochromis niloticus* are cultured. Diversification of fish species *i.e.*, culturing brackish water fish in freshwater and low salinity tolerant freshwater fish in brackish water has been a reality (Trvidei *et al*., 2015). This will provide flexibility and resilience in fish culture. Several stress-tolerant species such as *Pangasianodon hypophthalmus*, *Anabas testidienus* and *Channa straiatus* have been identified for stress conditions (Kumar *et al*., 2018).

## Conclusions

Agriculture causes climate change and also suffers from the consequences. Adaptation and mitigation options are available to compensate the loss and get a stable production. Most of these are no-regret options and linked to achieving the SDGs. Moreover, productivity can be further increased as currently we are harvesting only 50-60% of the genetic potential of most crops. Institutions, however, need to be reshaped towards resource conservation and climate-resilience. Creating awareness among farmers, policy makers and extension personnel on the impacts of technologies for climate risk mitigation is equally important. Finally, to make Indian agriculture climate-smart, we need smart farmers. We need to start from the grass-root with a strong policy support for sustainable production, processing, pricing, procurement and promotion of climate-smart technologies.

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# Conservation Agriculture and Sustainable Development Goals in South Asia

**M.L. Jat[1] and S.K. Chaudhari[2]**

[1]*International Maize and Wheat Improvement Center (CIMMYT), South Asia Regional Office, Kathmandu, Nepal*
*Email: M.Jat@cgiar.org*

[2]*Deputy Director General, Natural Resource Management, Indian Council of Agricultural Research, KAB-II, Pusa New Delhi, India*

## Introduction

Global agriculture and food production, primarily driven by technology-led enhanced productivity, had doubled during the past three decades. This enabled the developing world to reduce the numbers of hungry people from 994 million in 1992 to 791 million in 2014, a decrease of 203 million in 22 years. As per a new UN report, in 2019, almost 690 million people in the world were undernourished– that's 8.9% of the world population and this figure could exceed 840 million by 2030, if current trends continue. Food insecurity; both moderate and severe has "consistently increased" since 2014, when the prevalence of under-nourishment was at 8.6%. Between 2018 and 2019, the number of hungry people grew by 10 million people. The majority of this increase has come from Asia, where the majority of undernourished people live; some 381 million.

Moreover, South Asian agriculture is a global 'hot spot' for contemporary and future climate vulnerability. Further, 1.7 billion people live in South Asia and by 2050, that number is expected to rise to 2.4 billion. Although the region enjoys high economic growth, it suffers from extreme poverty, undernourishment, and the deterioration of natural resources. South Asia has more than 42% of the world's poor earning with less than US$ 1.90 per day, about 21% of the population is undernourished, and more than 41% of children are underweight. Rapid population growth will increase the demand for cereals by about 43% between 2010 and 2050. Meeting this projected need is doubly challenging considering 94% of the land suitable for farming is already in production and 58% of agricultural areas face multiple climatic hazards such as water shortage and extreme heat stress. The present situation is anticipated to worsen with climate change, with rising temperature and changing monsoon rainfall patterns projected to cost India 2.8% of gross domestic product (GDP). Although global crop productivity has more than doubled during the last decades, negative impacts on environment, biodiversity, soil quality, and air quality are common.

The natural resources in South Asia/India are highly stressed due to increasing population, economic and political pressures compared to the rest of the world and can potentially add to adversity of climatic risks. Agriculture's contribution to the Sustainable Development Goals requires climate-smart and profitable farm innovations such as conservation agriculture based sustainable intensification strategy. Therefore, future food production in South Asia/India requires new management approaches that are efficient, and climate smart to make tangible contributions to the

UN's Sustainable Development Goals (SDGs). Moreover, the future food and nutrition security in South Asia/India has major challenges of natural resource fatigue, decelerating productivity growth of food grains and changing food habits towards non-vegetarian diets. These challenges are further exacerbated due to sharp rise in the cost of inputs including energy, depleting water resources, soil degradation, indiscriminate and imbalanced use of chemical fertilizers and above all the adverse effect of global climate change.

In South Asia/India, more than 95% of agriculturally suitable land is already under cultivation. Hence, there is no scope for horizontal expansion of farming. Nonetheless, having high risks of climate change induced extreme weather events, the crop yields in the region are predicted to decrease between 7–10% in near future. Therefore, development and deployment of tools, techniques, practices and strategies aiming at increasing agricultural production, while arresting degradation of soil, water and environment and ensuring their rational use are essential to meet the future food demands in the region. Therefore, there is need for a paradigm shift in agronomic management practices to not only produce more but with higher efficiency of inputs used. For this, now conscious efforts are needed to swap the unsustainable elements of the conventional-tillage-based monoculture production paradigm with temporally and spatially high productive, profitable sustainable intensification.

## Conservation Agriculture - A snapshot

Conservation Agriculture (CA) is an ecosystem approach to regenerative agriculture and land management systems based on three interlinked principles: (1) continuous minimum mechanical soil disturbance using no-till or reduced tillage based crop establishment, (2) maintenance of permanent soil cover using crop residues and cover crops and (3) diversification of cropping system using economically, environmentally and socially adapted rotations including legumes and cover crops coupled with other complementary good agronomic management practices. Globally, CA has been adopted with less than 1 million ha in 8 countries in 1970 to 205 million ha in 102 countries in 2019 which is 15% of the world's cropland area. In Argentina, Australia, Brazil, Canada, Paraguay, South Africa, Uruguay and the USA, CA methods are applied on more than half their cropped area. From 1990 to 2009, the CA area globally increased at an average annual rate of 5.2 million ha, reaching about 100 million ha in 2008. Whereas from then on until now, the CA area expanded at double that rate, attaining an average of 10.5 million ha per year. CA aims to achieve sustainable, resilient and profitable agriculture and subsequently leads to improved livelihoods of farmers through the application of three CA principles. Therefore, CA has emerged as an alternative to an inefficient tillage-based conventional agriculture. Numerous favorable impacts have been reported in the global literature on CA including for crop yields, resource (labor, water, energy) use efficiencies, timeliness of cropping practices, soil quality and ecosystem services which are summarized in Fig 1.

## Conservation Agriculture in South Asia

In South Asia (India in particular), over past 2 decades, a considerable attention has been given to conservation agriculture (CA) as a 'sustainable intensification' strategy, but there is a lack of evidence-based consensus, human resource capacity and knowledge on the merits of CA in the context of local situations. There has been gradual increase in adoption of CA over time. Zero-till wheat has been adopted on a significant area in the rice-wheat system of the Indo-Gangetic Plains of south Asia, with positive impacts on wheat yield, profitability, and resource-use efficiencies, improvement in soil health and reduced greenhouse gases and air pollution.

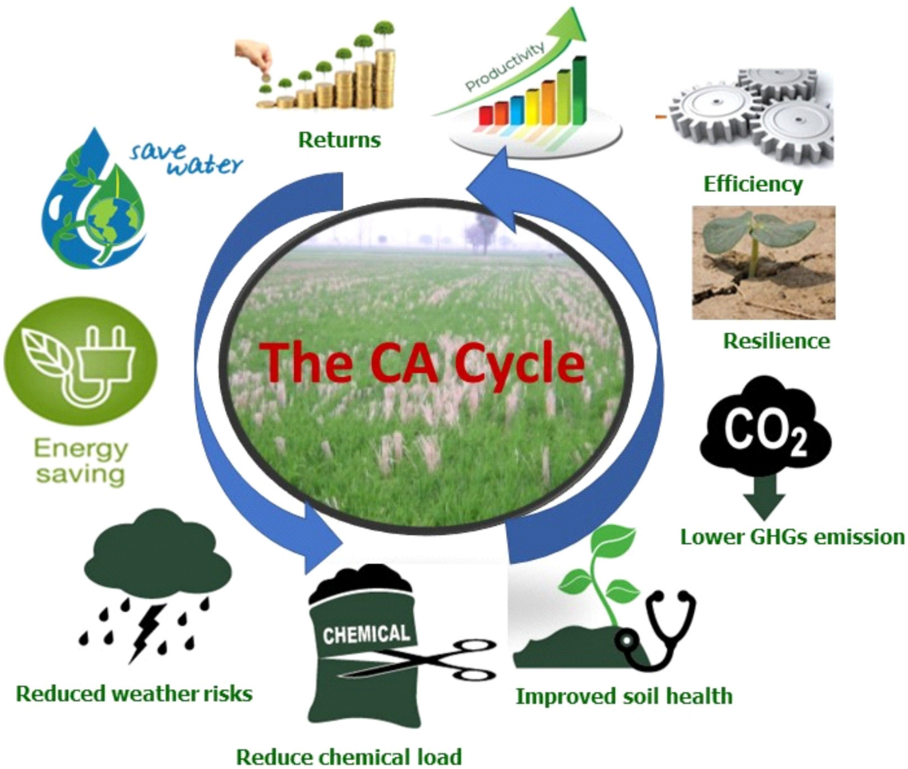


**Fig. 1.** Potential benefits of the Conservation Agriculture

The national governments in South Asia are actively promoting CA to address the challenges of agricultural sustainability. The synthesis of CA research through meta-analysis of large datasets across South Asia have generated evidence on performance of CA on key parameters (yield, protein, water, profits, GHGs, soil health, adaptive capacity to climatic risks, etc.) which shows that CA not only has multiple benefits but also has potential to contribute to the UN Sustainable Development Goals through alleviating the multiple stresses including emerging social issues currently faced by agriculture in South Asia/India. The results of meta-analysis of CA based practices in South Asia shows a mean yield advantage of 5.8% with 12.6% higher water use efficiency, an increase in net economic return of 25.9% and a reduction of 12–33% in global warming potential while building soil carbon, reducing the climatic risks (Jat *et al*., 2020).

However, the response for different indicators varies under various management circumstances (cropping systems, soil types, agro-ecologies, farmer circumstances etc.). The analysis further suggests significant, if not transformative, benefits when CA component practices are implemented either separately or in tandem. For example, zero tillage with residue retention had a mean yield advantage of 5.2%, irrigation water savings of 9.8%, reduction in costs of cultivation by 14.2% and increase net returns by 27.5%. Evidence also suggests a reduction of 12-33% in the global warming potential with full CA adoption. Results further suggest that CA and it's component technologies provide real benefits in the cereal systems of South Asia, especially for its potential for increasing net returns, and there are opportunities for improved technology targeting to maximize expected benefits.

The Conservation Agriculture (CA) concept with locally adapted component technologies has worked well under diverse crops, cropping systems, soil types and agro-ecologies including irrigated, rainfed and hill farming systems. In terms of climate change adaptation and yield gains, CA has more potentially opportunities in rainfed and fragile agro-ecosystems not only with respect to yield, income, resource conservation but also for mitigating the climatic risks and minimizing environmental footprints. CA also provides economically viable and environmentally sound opportunities for eliminating crop residue burning which is major cause of concern for air pollution (Shyamsunder *et al.*, 2019; Hellin *et al.*, 2021).

**Fig. 2.** A typical Conservation Agriculture Field in IGP

### *A top-up on the three principles of Conservation Agriculture is needed for the success*

There has been a significant advancement in various Conservation Agriculture based technological interventions for a food- and water-secure world. However, commodity and component centric, area-general *ad hoc* recommendations are no longer helping farmers. Therefore, developing and targeting portfolio of component technologies through bundling on a system basis and defining their recommendation domains are critical for the needed investment decisions for impact at scale (Jat, 2020). Science evidence indicates to address the growing challenges of yield stagnation, water, energy and labour shortages, deteriorating soil health and climate change-induced variability in intensive cereal-based systems, the recent research innovations on portfolios of practices for Sustainable Intensification and climate-smart agriculture through bundling CA with other component technologies such as laser leveling, soil moisture tension based irrigation scheduling, sub-surface drip fertigation, automated irrigation etc. have shown promise (Sidhu *et al.*, 2021). Fully validated science based evidence on conservation agriculture have demonstrated that system based targeted CA-based management practices portfolio has potential to produce more (10-15%) food from less water (20-75%) & energy (20-45%) while increasing farmers income (25-50%) in an environmentally responsible manner through lowering carbon foot prints by 25-30% (Jat *et al.*, 2019). A system-based research on rice-wheat rotation by Jat *et al.* (2009) showed complementing effects of layering laser land leveling and conservation agriculture on crop and water productivity and economic returns. Studies conducted by Kakraliya *et al.* (2018) in a rice-wheat (RW) rotation of western IGP revealed that layering of various management practices over CA in RW rotation improved system productivity and profitability by 6 and 19% respectively, and saved 22% of irrigation water and improved WPI and WPI+R by 37 and 26% on a 3 yrs' mean basis, respectively compared to farmers' practice while reducing 40% global warming potential (GWP). In addition, the bundled deployment of these practices was found more adapted to climate risks rather than conventional practices. Sandhu *et al*. (2019) reported that layering drip irrigation with residue retention in a no-till maize wheat system, saved 25. 5 cm water in a sandy loam soil and increased water productivity by 66% and 259% in wheat and maize respectively compared to the conventional tillage-based furrow irrigated system. Results from another set of research showed that CA coupled with sub-surface drip irrigation (SDI) in a rice-wheat system saved about 50 per cent water and improved yields by 10–20% by eliminating surface water evaporation and reducing the incidence of weeds (Sidhu *et al*., 2019). The amount of energy required to pump groundwater is about 50% less with an SDI system; the improvement in irrigation water-use efficiency resulted in higher net returns. In a recent study by Jat *et al*. (2019), bundling of conservation agriculture (CA) with sub-surface drip irrigation termed as CA+ were compared with CA alone and conventional tillage-based flood irrigated RW rotation (Table 1). In contrast to conventional till RW rotation which consumed 1889 mm $ha^{-1}$ irrigation water, CA+ system saved 58.4 and 95.5% irrigation water in rice-wheat (RW) and maize-wheat (MW) rotations, respectively. On a system basis, CA+ practices saved 46.7 and 44.7% irrigation water under RW and MW systems compared to their respective CA-based systems with flood irrigation. CA+ in RW system recorded 11.2% higher crop productivity and improved irrigation water productivity by 145% and profitability by 29.2% compared to conventional farmers' practice. Substitution of rice with maize (MW system) recorded 19.7% higher productivity, saved 84.5% of irrigation water and increased net returns by 48.9% compared to farmer's practice. CA+ RW and

**Table 1.** Performance of bundled application of conservation agriculture, diversification and sub-surface fertigation in intensive cereal systems

| Management scenarios | System grain yield ($t\ ha^{-1}\ yr^{-1}$) | Net economic return (USD $ha^{-1}\ yr^{-1}$) | Irrigation ($mm\ ha^{-1}$) | $WP_I$ (kg grain $m^{-3}$) | PFPN (kg grain $kg^{-1}$ N applied) | Energy use efficiency ($MJ\ ha^{-1}$) |
|---|---|---|---|---|---|---|
| **Business as usual:** *conventional tillage-based flood irrigated rice-wheat (RW) system* | 13.37 | 1874 | 2321 | 0.58 | 41.13 | 4.90 |
| **Intensification of RW system:** *Rice-wheat-mungbean with CA and flood irrigation* | 14.03 | 2152 | 2004 | 0.70 | 45.25 | 5.76 |
| **Diversification of RW system:** *Maize -wheat (MW)-mungbean with CA and flood irrigation* | 15.33 | 2648 | 651 | 2.37 | 47.17 | 10.30 |
| **Sustainable Intensification of RW system:** *Rice-wheat-mungbean with CA and sub-surface fertigation* | 14.87 | 2421 | 1068 | 1.42 | 59.46 | 7.90 |
| **Sustainable Intensification of MW system:** *Maize -wheat-mungbean with CA and sub-surface fertigation* | 16.00 | 2791 | 360 | 4.46 | 61.52 | 12.16 |

Adapted from Jat *et al*. (2019)

MW system improved energy productivity by 75 and 169% and partial factor productivity of N by 44.6 and 49.6%, respectively compared to conventional tillage based RW system

## Conservation Agriculture and Sustainable Development Goals

Agriculture's contribution to the Sustainable Development Goals (SDGs) requires climate-smart and profitable farm innovations such as Conservation Agriculture based sustainable intensification. Various types of management strategies in Agri-Food systems have negative as well as positive linkages with different Sustainable Development Goals (SDGs). Fig. 3 depicts the linkages of subsistence agriculture, conventional agriculture as well as Conservation Agriculture with different SDGs. While subsistence and conventional agriculture has negative linkages with 12 of the 17 SDGs, the science evidence described in above section reveals that Conservation Agriculture has direct positive linkages with 8 SDGs and indirect positive linkages with remaining 9 SDGs through enabling policies. Therefore, CA has a potential role to play for achieving the SDGs.

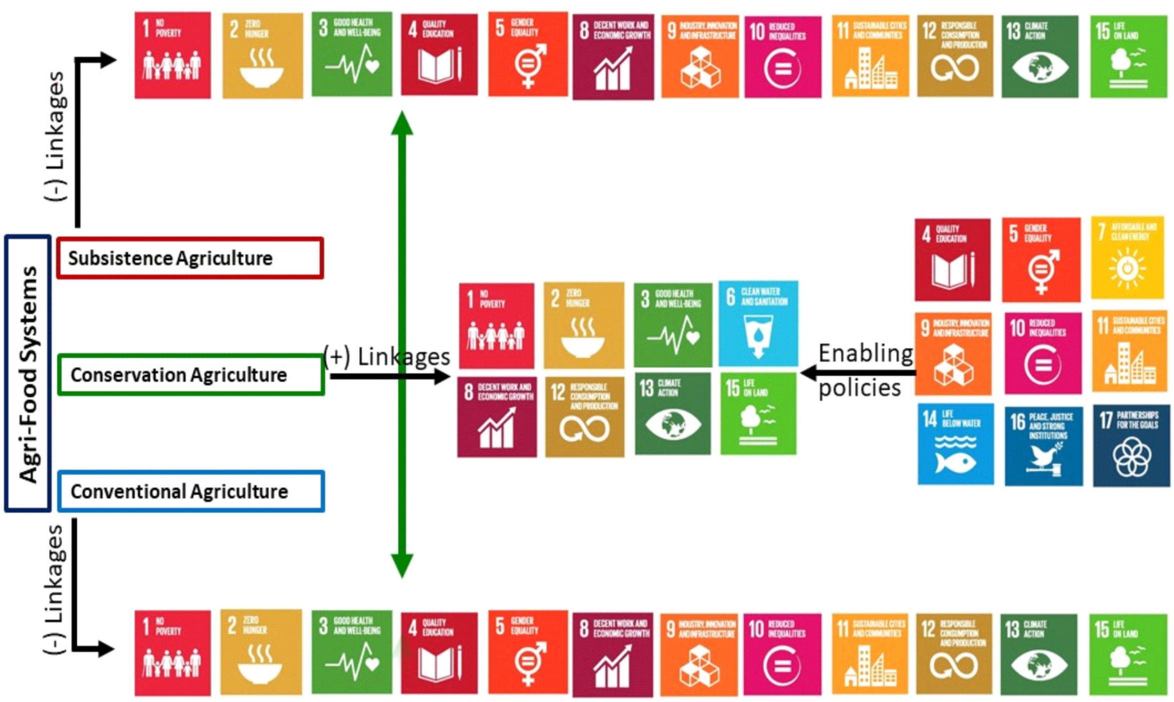


**Fig. 3.** Inter-relationship of Conservation Agriculture and conventional food production systems with SDGs

## Barriers to adoption of Conservation Agriculture

While, Conservation agriculture have shown potential benefits across different production systems, geographies and farmer circumstance, yet the adoption remained slow due to several barriers and the major ones are listed below-

- Lack of system-based approaches
- Largely production focus and lack of multi-criteria analysis
- Lack of Theory of Change (ToC) at local, sub-national, national level
- Large knowledge and capacity gaps

- Silver bullet and ad-hoc recommendations and lack of location, -situation and -circumstance specific recommendations
- 'One Size Fits' all based investments and lack of science evidence-based targeting and investments (Policy)
- Lack of social and behavioural science communication and apprehensions/perceived risks v/s reality check?
- Lack of common neutral platform for learning, capacity, collective wisdom & action

## Roadmap for Accelerated adoption of Conservation Agriculture

For accelerated adoption of Conservation Agriculture in smallholder systems, a 10-point strategy is suggested (Adopted from Jat *et al*., 2018; NAAS, 2017; Paroda *et al*., 2018; TAAS, 2017, 2021, Mishra *et al*., 2020)

- ***Conservation Agriculture (CA) addresses several major challenges*** confronting agriculture including climate change, water scarcity, soil health deterioration, low farm profitability, environmental pollution and its adverse impacts on ecosystem and human health. As such, CA contributes to at least 8 of the UN's Sustainable Development Goals (SDGs) and should be valued by policy planners accordingly.
- Several well-executed research programs have generated significant knowledge of CA performance over past 2 decades. However, due to spatial, and management factors, response cannot be generalized. Therefore, there is a need to ***better aggregate and map knowledge of CA across production circumstances in order to define recommendation domains*** that consider soil, climate, cropping systems and socio-economic conditions.
- While ***there is a strong need for strengthening the long-term CA research platforms*** as **'Living Labs'** to generate new science evidence and capacity development and linking those with ***on-farm research-cum-demonstration with farmers' participation*** for validating CA performance on a broader spatial scale, including identification of adoption bottlenecks.
- ***Commercial availability of scale appropriate machinery*** is one of the critical factors for success of CA. Hence, CA mechanization priorities need to be defined and strengthened in the regions having week manufacturing capacity and distribution channels. Special emphasis should be made on establishing CA mechanization hubs in rainfed ecologies and eastern IGP.
- ***Soil biology and pest (including insects, pathogens) dynamics under CA*** needs a thorough investigation due to change in hydro-thermal, carbon and nutrient regimes of the soil in presence of crop residue cover and non-disturbance of soil. Changes in community structure and dynamics of microbial mediated processes under CA need to be evaluated to harness the benefit.
- By synthesizing all the evidence generated on CA across the diversity of production system and ecologies over past 2 decades, a strong case needs to be made for a ***'Conservation Agriculture Consortium (CAC)'***. Emphasis is to be laid on CA for rainfed agriculture. Under this CAC some strategic sites should be identified and established as 'Living Labs' on CA under ***deficit, limited*** and ***adequate*** water availability situations
- ***Scalable and sustainable business models*** should be developed for promoting adoption of CA in large scales through Motivating and Attracting Youth in Agriculture (MAYA) and empowering women for creating effective custom hiring centers as well as manufacturing hubs. Enhanced capacity development of all stakeholders involving farmers service providers-scientists-to policy planners should be an integral part of such models.

- ***CA should be the part of course curriculum*** of undergraduate and post-graduate courses in all the Agricultural Universities. The Education Division of ICAR may take appropriate action to initiate such courses. In all the agricultural universities as well as ICAR research institutions and KVK farms, there should be large-scale demonstrations of CA-based systems for training of young researchers. The practical crop production program at undergraduate level by the students should be mandated for CA-based production system.
- Given the significant contributions of agriculture in GHG emissions, there is a need for creating a pull factor for transforming CA by incentivizing farmers for ***Carbon Credits/eco-system services*** through repurposing subsidies and developing carbon markets for private sector
- There is a need to ***establish a learning platform/CA-Community of Practitioners (CA-CoP)*** with a mechanism for regular interactions, knowledge sharing and capacity development. Accordingly, a ***'Technical Working Group on Conservation Agriculture (TWGCA)'*** involving key researchers from ICAR, SAUs, CIMMYT, other CG Centers and other organizations should be established as **"The India CA Center"** with defined roles and responsibilities to promote CA in India. The Center should be mandated to work on (i) mapping CA research and development initiatives, (ii) defining recommendation domains of CA-based management systems, (iii) identifying research gaps and address pertinent questions and concerns related to CA, (iv) acting as knowledge repository and sharing center, (v) serving as catalyst for capacity development of stakeholders, (vi) developing science-driven policy guidelines and advisories for out-scaling CA, (vii) developing proposals and raising funding for CA research and development, (viii) acting as facilitator for south-south collaboration, (ix) developing framework for tracking adoption and social impact of CA and (x) monitoring and evaluating CA adoption and its impacts.

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# Agricultural Water Management Technologies for Climate Change Adaptation

**Gouranga Kar**

*ICAR–CRIJAF, Barrackpore, West Benal*
*Email: kar_wtcer@yahoo.com*

## Introduction

Changing climatic patterns coupled with declining per capita availability of land and water resources of India have create a great challenge for sustainable agriculture. The water resources potential of India which occurs as natural runoff in the rivers are estimated at about 186.9 M ha-m. Considering both uneven distribution of water resource over space and time about 112.2 M ha-m of the total potential can be put to beneficial use, 69 M ha-m through surface water resources and 43.2 M ha-m by groundwater (Kumar and Kar, 2013). India also experiences high degree of spatial variability of annual rainfall, highest annual rainfall of 11,690 mm is recorded at Mousinram near Cherrapunji, Meghalaya, and lowest of 150 mm at Jaisalmer, Rajasthan. Average 75% precipitation of the country occurs during southwest monsoon season (June to September) only. For adequate living standards as in western and industrialized countries, a renewable water supply of at least 2000 $m^3$ per person per year is necessary (Postel, 1992). If only 1000-2000 $m^3$ per person per year is available, the country is 'water stressed', while the value comes below 500 $m^3$ per person per year, the country is called 'water scarce' (Bouwer, 2000). With the population of India expected to stabilize around 1640 million by the year 2050, the gross per capita water availability will decline from 1820 $m^3$/person/year in 2001 to as low as 1140 $m^3$/person/year in 2050 and the country will be entered into the 'water stress' category (Kumar and Kar, 2013). With rapid population growth and rising expectation of better life, there will be ever increasing demand of water for various competing sectors like domestic, industrial and agricultural needs. Also more and more water will be required for environmental concerns such as aquatic life, wildlife refuges and recreation.

Therefore, the available land and utilizable water resources would be inadequate to meet the future demand unless these precious resources are utilized precisely and efficiently. Adoption of suitable agro-techniques and water management practices are need of the hour to produce 'more crops per drop' that is to enhance water productivity so to check the decline of surface and ground water resources in India.

## Impact of Elevated Temperature on Crop Evapo-Transpiration and Water Footprints of Some Winter Season Crops

As per the multi-model analysis (IPCC7), increase of global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to likely be in the ranges derived from the concentration-driven CMIP5 model simulations, that is, 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), 2.6°C to 4.8°C (RCP8.5). The rate of warming has been much higher in recent decades. This has, in turn, resulted in increased average temperature of the global ocean, sea level rise, decline in glaciers and snow cover. Climate change due to increase in temperature rise will demand higher amount of water for irrigation. At the same time the higher temperature will change the crop physiology and shorten the crop growth period which in turn will reduce the irrigation days. These contradictory phenomena will change the total irrigation water demand which is required to quantify for long-term water resources planning and management. As a case study the crop water requirements of some winter season crops of Dhenkanal, Orissa under current and projected climate change scenario (RCP 4.5 and 8.5) were determined and are given in Table 1 (Kar *et al*., 2014).

**Table 1.** Impact of elevated temperature on crop evapo-transpiration (ETc, mm) of some winter season crops under scenario of RCP 4.5 (Study area: Dhenkanal, Odisha: Sowing – last week of November)

| Crops | Current ETc (mm) 2010 (4.5) | 2050 RCP (4.5) | % Increase from Current | 2070 RCP (4.5) | % Increase from Current | 2095 RCP (4.5) | % Increase from Current |
|---|---|---|---|---|---|---|---|
| Potato | 409.4 | 425.3 | 3.9 | 434 | 6.0 | 442 | 8.0 |
| Blackgram | 332.5 | 345.1 | 3.8 | 354 | 6.5 | 358 | 7.7 |
| Sunflower | 426.7 | 443.2 | 3.9 | 457.6 | 7.2 | 461 | 8.0 |
| Wheat | 396 | 415 | 4.8 | 424 | 7.1 | 434 | 9.6 |
| Chickpea | 377.6 | 391 | 3.5 | 402 | 6.5 | 409 | 8.3 |
| Safflower | 414.1 | 430.2 | 3.9 | 442.8 | 6.9 | 445 | 7.5 |
| Mustard | 375.1 | 389.6 | 3.9 | 397 | 5.8 | 403 | 7.4 |
| Linseed | 281.2 | 291.5 | 3.7 | 298 | 6.0 | 305 | 8.5 |
| Rapeseed | 331.4 | 343.9 | 3.8 | 351 | 5.9 | 357 | 7.7 |
| Tomato | 514.6 | 534.9 | 3.9 | 545 | 5.9 | 553 | 7.5 |
| Cabbage | 500.5 | 515 | 2.9 | 528 | 5.5 | 538 | 7.5 |
| Cauliflower | 496.1 | 510 | 2.8 | 524 | 5.6 | 535 | 7.8 |
| Okra | 420.7 | 432.6 | 2.8 | 443.6 | 5.4 | 450.3 | 7.0 |
| Carrot | 398 | 409.2 | 2.8 | 421.5 | 5.9 | 427.4 | 7.4 |
| Rice | 605 | 618 | 2.1 | 633 | 4.6 | 643 | 6.3 |
| Groundnut | 376 | 385 | 2.4 | 396 | 5.3 | 404 | 7.4 |
| Maize | 380 | 391 | 2.9 | 404 | 6.3 | 412 | 8.4 |

### *Suitable agro-techniques and water management practices to enhance water productivity, water use and irrigation efficiency*

Strategies to enhance water use efficiency and irrigation efficiency which includes improved irrigation system management to provide more reliable water supply to farmers through storage and improved operation of reservoirs, better distribution of water with improved control structures as well as more responsive management. More reliable water supply allows farmers to invest in better on-farm water management such as better land leveling, zero tillage, or pressurized irrigation. Improved management usually requires improved institutions as well as improved technologies. Irrigation efficiency mainly depends on loss of water in conveyance system including distribution system and in the field. Loss of water in conveyance system is mainly due to seepage and evaporation. Evaporation loss takes place from the exposed water surface. Some of the strategies needed to improve water and irrigation use efficiency under rainfed and irrigated agriculture are discussed below.

### *Rainwater harvesting and management*

Rainfed farming will remain the main stay for the livelihood support of millions of small and marginal farmers across the country even after realizing the complete irrigation potential. Rainfed agriculture is complex, diverse and risk-prone and will be mostly affected by climate change. This rainfed land is characterized by low levels of productivity and variability in rainfall results in wide variation and instability in yields. The challenge before Indian agriculture is to transform rainfed farming into more sustainable and productive systems and to better support the population dependent upon it.

Rainwater management is the most critical component of rainfed farming. The successful production of rainfed crops largely depends on how efficiently soil moisture is conserved in situ or the surplus runoff is harvested, stored and recycled for supplemental irrigation. India has a long history of rainwater harvesting through a variety of structures and systems (tanks, ponds etc.), which are built by the Government and local bodies and managed by the community and village level Institutions. However, after independence, with the availability of electricity and pumping technology, private investment on tube wells has enormously increased and the tank systems were gradually ignored. The emphasis shifted from community based structures which use surface water to individual investments which exploited ground water.

Under the changed climate scenario for effectiveness of rainwater harvesting, emphasis should be given on the following issues:

- Best designs for different rainfall zones and soil types
- Optimum size of farm pond given the catchment area available under different farming situations
- How can the capital cost of farm ponds be reduced through convergence of other developmental programmes
- What are the innovations in checking evaporative losses, cost effective sealants, and water lifting devices for conveyance.
- What are the best options in terms of crop choices to realize the best returns from stored water
- How to resolve the issue of sharing water in case of small holders where catchment and command area belong to different farmers
- What are the on-site and off-site benefits including environmental pay-offs due to rain water-harvesting
- What are the indigenous techniques of rain water harvesting which can help farm pond technology become more cost effective?
- Potential of water harvesting through farm ponds in adaptation and mitigation of climate Change

Convergence of watershed developmental program with other programmes and schemes is the need of the hour for sustainability. A variety of component, commodity based sectoral schemes to integrate rainfed and dry-farming technology like NFSM, PMKSY, RKVY, NHM, Artificial Groundwater Recharge, MGNREGA, NRLM, NAPCC Mission Initiatives

## Watershed Plus

At present very high priority has been accorded by the government of India to the holistic and sustainable development of rainfed areas based on the watershed approach. Indeed, the watershed approach represents the principal vehicle for transfer of rainfed agricultural technology. A watershed (or catchment) is a geographic area that drains to a common point, which makes it an ideal planning unit for conservation of soil and water. A watershed may comprise one or several villages, contain both arable and non-arable lands, various categories of land-holdings and farmers whose actions may impact on each other's interests. The watershed approach enables a holistic development of agriculture and allied activities in the area taking into account various kinds of land-use based on crops, horticulture, agro-forestry, silvi-pasture and forests.

But the current watershed technologies should be further upgraded to diversify and enhance productivity, income, employment and environmental service under the changed climate scenario. This should include value addition, new varieties commodities, horticulture, livestock rearing, aquaculture with greater emphasis on high and low rainfall regions. Soil & water conservation, most efficient inputs, practices, seeds, enterprising especially by landless, equity and convergence are the upper most consideration of technology generation. Market and agro-industry driven employment generation, empowerment of local communities, *Panchayats* and women should be essential ingredients of all inclusive development process. Convergence of diverse resources of various ministries like MGNREGA, eco-afforestation, million wells, watershed allocation should generate critical mass and adequate synergies. Private-public-social capital linkage should target internalization of wastelands of private, *Panchayats* and public departments.

Recharging of aquifers in forest and gully lands by runoff from agricultural fields, wasteland, urban areas, metalled roads, flyover, etc. is essential. Contamination of groundwater recharging through shafts, abandoned bore wells, open wells. etc. is a larger technological challenge. This technological demand presumes latest art of modeling contamination, bio-remediation and convergence of non-traditional sectors, departments, agencies and resources.

### *Multiple use of water for enhancing water productivity*

Per captia availability of land, water and other natural resources is already low and declining further. Multiple use of water through agricultural diversification which has several components like poultry, duckary, fisheries, apiculture etc. along with diversified crop production or value added products has proved to be an effective means in mitigating drought and eliminating poverty as it provides high income, regular employment, and balanced and quality food, even with less water. As the agricultural diversification comprises of several farm enterprises in addition to diversified crops, it provides opportunity to farmers to have a 'basket of complementary options' for reducing the weather risks involved in single commodity based agriculture.

Water productivity can be improved by 5 to 7 times by integrated planning through multiple use of water. In pond based integrated farming, culturing fish in dug out pond, vegetables and horticulture on raised embankment can be grown. To enhance the productivity and profitability from harvested water, it has to be utilized for both consumptive and non-consumptive purpose. Fresh water Indian major fish species (Catla, Rohi, Mrigal) of 3 to 4 unit size @ 10,000/ha can be released into the pond during August. The stored water of the pond can be utilized for providing supplemental irrigations to grow *rabi* crops like groundnut, sesamum, mustard, sunflower, vegetables (cucumber, watermelon, okra and ridge gourd). The vegetables like tomato, cauliflower, brinjal, bottle gourd can be grown on the pond bund with the help of harvested water. Short duration fruit crops like papaya, banana can be grown on the pond bund. After adoption of pond based farming system, farmers' net returns were found to be higher by 3-4 times than that of earlier in a study at Balasore, Odisha.

### *Crop diversification with in-situ rainwater management*

Crop diversification refers to the addition of new crops or cropping systems to agricultural production on a particular farm taking into account the different returns from value- added crops with complementary marketing opportunities which can be grown with high resources use efficiency and with less water. Crop diversification with low water requiring crops through intercropping/ mixed cropping/sequential cropping will be useful for climate change mitigation also. Adoption of crop diversification helps in conservation of natural resources like introduction of legume in rice-wheat cropping system, which has the ability to fix atmospheric.

Crop diversification in rainfed rice field was implemented in Odisha on large scale with maize, (cv. Navjyot), pigeonpea (cv. UPAS-120), groundnut (cv. Smriti), blackgram (cv. T9) and cowpea(cv. Pusa Kamal) and their productivity and water use efficiency were compared with that of sole rice (cv. Vandana). Partial substitution of rice through rice based inter-cropping viz., *viz.*, rice+pigeonpea (4:1), rice + groundnut (4:1), rice + blackgram (4:1) was also practiced with proper weed management. Complete substitution of rice through legume based intercropping *viz.*, groundnut+pigeonpea (4:1), groundnut+greengram (4:1), groundnut + blackgram (4:1), groundnut + cowpea (4:1) were also implemented. Study revealed that water productivity and water use efficiency were enhanced by 2-3 times after adoption of crop diversification (Kar *et al.*, 2003). Crop diversification (sole cropping/intercropping) with low water requiring crops like maize, groundnut, blackgram, greengram, cowpea, pigeonpea etc. ensured higher net economic return in rainfed upland rice field even in rainfall deficit years when net return from sole rice was nil or negative.

### *Irrigation scheduling based on scientific approach*

Irrigation scheduling is a systematic method of deciding the quantity and timing of irrigation. It helps the irrigator to decide on when and how much water to apply for minimizing crop yields and efficiency of water use. The basic objective of Irrigation scheduling is to make available the correct amount of water for the biological processes of plants at appropriate time by applying the exact amount of water needed to replenish the soil moisture to the desired level. Irrigation scheduling becomes particularly sensitive under scarce water supplies where water shortage requires a refined timing of water application in order to minimize yield restrictions. A phenological based irrigation scheduling on maize was followed as per description in Table 2 and water productivity were compared.

A comparison of water productivity (CWP) between the treatments receiving irrigation at flowering and milk ripe-grain filling stages and not receiving irrigations at these stages with same amount of irrigation ($I_4$ and $I_5$) showed that water was more efficiently utilized when irrigation was not skipped at flowering and milk ripe-grain filling stages (Table 3). As for example with the same amount of irrigation (300 mm) in $I_4$ and $I_5$, less crop yield was obtained in $I_4$ because irrigation was skipped at flowering stage of the crop under this treatment. Better water utilization efficiency and higher CWP in treatment $I_5$ were obtained which might be associated with adequate water applied during flowering stage. This result implies that the crop growth stage at which deficit irrigations are imposed on the crop is also a determining factor to achieve higher CWP.

### *Pressurized irrigation system*

The water use efficiency under conventional flood method of irrigation, which is predominantly practiced in Indian agriculture, is very low due to substantial conveyance and distribution losses.

**Table 2.** Irrigation treatment for the field experiments

| Stages | Description | Irrigation (mm) treatments | | | | | |
|---|---|---|---|---|---|---|---|
| | | $I_1$ | $I_2$ | $I_3$ | $I_4$ | $I_5$ | $I_6$ |
| Stage 0 | Period of germination of seed in the soil | X | X | X | X | X | X |
| Stage 1 | Emergence of coleoptile from the soil and seedling growth up to 3 leaves unfolded | X | X | X | 60 | 60 | 60 |
| Stage 2 | Stem elongation (1): Internodes below 5th, 6th, and 7th leaves have begun to elongate | 60 | 60 | 60 | X | X | X |
| Stage 3 | Stem elongation (2): 8 to 11 leaves unfolded, stem elongation rapidly, internodes below 5th and 6th leaves are fully elongated | X | X | X | 60 | 60 | 60 |
| Stage 4 | Stem elongation (3): 12 to 15 or more leaves unfolded, stem still elongates, emergence of tassel from the whorl | 60 | X | 60 | 60 | 60 | 60 |
| Stage 5 | Flowering (start of pollen shedding, 50% pollen shedding, 50% silking, end of flowering) | X | 60 | 60 | X | 60 | 60 |
| Stage 6 | Water ripe stage of caryopsis, start of silk drying | X | 60 | 60 | 60 | 60 | 60 |
| Stage 7 | Milk ripe stage (milk to solid conversion of endosperm, but whole kernel content is still milky liquid) | X | X | X | 60 | X | 60 |
| Stage 8 | Dry ripe stage (kernel is no longer milky, reached physiological maturity) | X | X | X | X | X | X |
| Stage 9 | Ripeness | X | X | X | X | X | X |
| | Total irrigation during crop growth (mm) | 120 | 180 | 240 | 300 | 300 | 360 |

$I_1$, $I_2$, $I_3$, $I_4$, $I_5$, $I_6$ are irrigations treatments, X = No irrigations were applied
*Source:* Kar and Kumar (2015)

**Table 3.** Water productivity of maize under different irrigation and nitrogen levels (pooled data of two years)

| Irrigation treatments | GY (kg ha$^{-1}$) | NR (Rs. ha$^{-1}$) | IWA (mm) | ER + (mm) SPC (mm) | SCWU (mm) | $WP_{CWU}$ (kg m$^{-3}$) | $WP_{NR}$ (Rs. m$^{-3}$) |
|---|---|---|---|---|---|---|---|
| I. Irrigation treatments | | | | | | | |
| $I_1$ | $^{E}$2129 | 11661 | 120 | 131 | 251 | $^{D}$0.849 | $^{D}$4.65 |
| $I_2$ | $^{D}$2490 | 14910 | 180 | 127 | 307 | $^{D}$0.811 | $^{C}$4.86 |
| $I_3$ | $^{C}$3553 | 21977 | 240 | 118 | 358 | $^{B}$0.993 | $^{A}$6.14 |
| $I_4$ | $^{B}$3785 | 24065 | 300 | 112 | 412 | $^{C}$0.918 | $^{B}$5.84 |
| $I_5$ | $^{A}$4534 | 25806 | 300 | 105 | 405 | $^{A}$1.120 | $^{A}$6.37 |
| $I_6$ | $^{A}$4675 | 27075 | 360 | 99 | 459 | $^{B}$1.019 | $^{B}$5.90 |
| II. Nitrogen levels | | | | | | | |
| $N_1$ | $^{D}$2295 | 13155 | 300 | 114.8 | 365 | $^{D}$0.629 | $^{C}$3.61 |
| $N_2$ | $^{C}$2714 | 20526 | 300 | 116.8 | 366 | $^{C}$0.742 | $^{B}$5.61 |
| $N_3$ | $^{B}$3319 | 19871 | 300 | 115.6 | 366 | $^{B}$0.908 | $^{B}$5.44 |
| $N_4$ | $^{A}$4385 | 29465 | 300 | 114.5 | 365 | $^{A}$1.203 | $^{A}$8.08 |
| $N_5$ | $^{A}$4525 | 25725 | 300 | 115.5 | 365 | $^{A}$1.239 | $^{A}$7.04 |

GY = Grain yield; NR = Net return; IWA - Irrigation water applied ER = Effective rainfall; SPC = Soil profile contribution; SCWU = Seasonal crop water productivity; WPcwu = Water productivity in terms of crop water use; $WP_{NR}$ = Water productivity in terms of net return in rupees; $WP\$_{NR}$ = Water productivity in terms of net return in US dollar
$I_1$, $I_2$, $I_3$, $I_4$, $I_5$, $I_6$ are irrigations treatments (Table-5) and $N_1$, $N_2$, $N_3$, $N_4$, $N_5$ are nitrogen treatments

Recognizing the limited irrigation water potential available and increasing demand for water from different sectors, a number of demand management strategies and programmes have been introduced to save water and increase the existing water use efficiency in Indian agriculture. One such method introduced relatively last few decades in Indian agriculture are pressurized irrigation systems, which includes both drip and sprinkler method of irrigation. Since, these methods need water under pressure, they are classified as pressurized irrigation systems. Pressurized irrigation system is a well-established efficient method for saving water and increasing water use efficiency as compared to the conventional surface method of irrigation (Table 4).

**Table 4.** Irrigation efficiencies in pressurized irrigation system

| Factors | Sprinkler irrigation system | Drip irrigation system | Surface irrigation system |
|---|---|---|---|
| Overall irrigation efficiency | 50-60% | 80-90% | 30-35% |
| Application efficiency | 70-80% | 90% | 60-70% |
| Water saving | 30% | 60-70% | NA |

Kumar and Kar (2013)

### *Drip irrigation*

Drip irrigation is an efficient method of providing irrigation water directly in to the root zone of plants and it permits the irrigation to limit the watering closely to the crop water requirement of plants. It also permits the utilization of fertilizers, pesticides and other water soluble chemicals along with the irrigation water. The system applies water at low rate and under pressure to keep the soil moisture within the desired range for plant growth. The system has overall application efficiency around 90% as compared to 25–30% for surface irrigation.

### *Sprinkler irrigation system*

Role of the sprinkler irrigation system has been universally acknowledged in achieving high water use efficiency, in improving crop productivity, quality of produce, saving of irrigation water and labour costs. The sprinkler irrigation system simulates the water application as of rainfall. The overall efficiency of sprinkler method is a high at 65% as compared to 25-30% of surface method or irrigation. The system has an advantage for the close growing crops in supplying the required quantity of water. This saves the irrigation water and helps in uniform application of water in the field. To adopt sprinkler system, a farmer has to incur an average cost of Rs. 15,000 per hectare. Sprinkler systems are classified either on the basis of the arrangement for spraying irrigation water or on the basis of their portability. In India, the rotating head portable systems are most commonly being used by the farmers.

### *Irrigation layout*

At field level, there is scope for increase application efficiency by proper land levelling, optimal plot size and improved irrigation methods. Basin irrigation is the most practiced method in India where water control is carried manually. Irrigators usually cut off the supply when advance is complete. Additionally irrigation water simultaneously infiltrates while advancing especially opportunity time is more near the entrance and more so during first post sowing-irrigation when surface soil is opened up with pre-seeding tillage. Both these factors induce large non-uniformities in water application in addition to over-irrigation. Based upon soil texture, slope and stream size, the cut-off ratios and basin sizes have been standardised for increasing irrigation efficiencies.

### *Improving water use efficiency of canal command*

Considerable amount of water is lost in canal command through evaporation, seepage and percolation. In no irrigation project in India the total losses in the canal distribution system & field has been less than 50% of the head discharge. A review of 90 irrigation projects of the world indicated generally low irrigation efficiencies, with only 20-40 % of water diverted from the reservoir being effectively used by the crop, while in India, the irrigation efficiency is around 10-20%. The losses of irrigation water are unlined canal distribution system in north India is given in Table 5.

**Table 5.** Losses of irrigation water in unlined canal distribution systems and in the field

| Source of loss | % of supplies at canal head | | |
|---|---|---|---|
| | Seepage | Evaporation | Total |
| Main canals and branches | 13.6 | 3.4 | 17.0 |
| Distributaries (10% of supply at distributor) | 6.4 | 1.6 | 8.0 |
| Field water courses (27% of supply at outlet head) | 16.0 | 4.0 | 20.0 |
| Losses from field during application (30% of supply reaching the head) | 13.2 | 3.3 | 16.5 |
| Total | 49.2 | 12.3 | 61.5 |

Kumar and Kar (2013)

In any irrigation project, the total losses in the canal distribution system and field has not been less than 50% of head discharge. Studies conducted in Nagarjuna Sagar Project have revealed that only 40-60% of water released from the reservoir reaches the field and only 20-40% is used by the crops. The main component of water losses in an irrigation system are (a) water losses in storage-10-20% (b) water losses in conveyance systems 25-40% (c) water losses in operation 10-30% and (d) water losses in application 45-70%. To increase the overall irrigation efficiency of 40-50% for a project, improved irrigation and drainage practices should be adopted based on scientific land water management principles. The method to reduce conveyance losses are by lining the bed and sides of the canal, eradication of weeds, reduction of wastage from escapes and tail ends. The use of plastic films as lining material also has tremendous scope in India.

### *Water saving technologies in canal command*

Irrigated agriculture can be made vibrant by increasing farm productivity in the country through scientific and efficient management of canal systems and water production can be enhanced through adoption of water saving technologies. Rotational irrigation is often recommended to irrigate a large area with a limited water supply and to ensure better equity among water users. Rotational irrigation is the application of required amounts of water to fields at regular intervals. The field may often be without standing water between irrigations, but ideally the soil does not dry enough for moisture stress to develop. A major advantage of rotational irrigation is possibly the more effective use of rainfall. Plant height, tiller number, leaf area index, dry matter production and grain yield generally decrease as the irrigation interval increases from 4 to 10 days (Table 6).

**Table 6.** Effects of rotational irrigation in IR 20 rice variety

| Irrigation interval (days) | Plant height (cm) | Tillers (No. hill) | LAI | Total dry matter (g/hill) | Yield (t/ha) |
|---|---|---|---|---|---|
| 4 | 102 | 18 | 6.5 | 53 | 7.2 |
| 6 | 97 | 18 | 54 | 47 | 7.1 |
| 8 | 98 | 17 | 5.2 | 49 | 6.8 |
| 10 | 92 | 12 | 4.2 | 37 | 5.6 |

*Source:* Reddy and Reddy (2009)

The results of experiments conducted by WALAMTARI on rice in Andhra Pradesh under Sriramasagar Project in sandy loam soils are given in Table 7.

**Table 7.** Saving in water due to rotational Irrigation for rice crop

| Irrigation interval (days) | Quantity of water applied (mm) | Yield of rice (kg/ha) | Reduction of yield % | Water Saved (%) |
|---|---|---|---|---|
| 1 | 1717 | 6324 | - | - |
| 2 | 1117 | 6056 | 4.42 | 34 |
| 3 | 1027 | 5924 | 6.75 | 40 |
| 4 | 913 | 5720 | 10.55 | 46 |
| 5 | 877 | 5646 | 12.00 | 48 |

*Source:* Reddy and Reddy (2009)

### *Re-use of irrigation water*

About 30% of water applied to the field is lost as surface or sub-surface flow and reaches drains. The water that reaches the drains can be stored at suitable sites and pumped back for irrigation by giving due consideration of water quality related issues.

### *Better operation planning*

Irrigation system operation is the process of releasing, conveying and diverting water in the canal systems to ensure pre-determined flows at prescribed times for specified duration at all designated points of delivery. The operation plan takes into account the water available in the reservoir at the beginning of each crop season and spells out the starting date of release of water, the mode of supplies i.e. whether intermittent and continuous, the detailed schedule of releases and the closing date of release of water. The operation plan is prepared with active participation and involvement of farmer's representatives so that it may be implemented without any resistance from the farmers. This will reduce wastage and better utilization of irrigation water will be ensured.

### *Systematic canal operation*

The object of systematic canal operation is to ensure equitable distribution of available flows at the heads of all off-takes on a distributary. A schedule of canal operation has to be prepared in advance. For instance, a distributary may be divided into seven reaches each covering one or more off-takes whose total discharge is about a seventh of the designed discharge of the distributary. One-seventh of the total discharge can he saved on each day by closing the off-take in each reach for 24 hours in succession in a week. This water can be made available to tail-enders and thus it will help saving water besides not having dry tail-enders problem.

### *Response to rainfall in canal operations*

Canal operations should respond meticulously to rainfall in the command area for efficient use of storage water in the reservoir. The demand of crops for water is met in the wet season by both rainfall in the command area and water stored in the reservoir. Water requirement of crops is worked out using one of the empirical methods suggested by FAO, Rome. The most common method used is Penman-Monteith (1996) method. While assessing the water requirements of crops during the wet season for preparing the operation plan, effective rainfall worked out from the data of average rainfall over a period during the past 20 years is deducted from the water requirements of crops worked out by the Penman-Monteith (1996) method or any other empirical method. But in real time situations, the pattern and amount of rainfall varies influence the scheduled deliveries. When rainfall is in excess, the scheduled irrigations are skipped and when rainfall is deficient unscheduled deliveries have to be made. This will ensure maximum utilisation of rainfall as well as protecting the crops from water stress or from excess water.

Irrigation deliveries are based mainly on the status of water balance in the cropped fields. The water balance in paddy fields is on the basis of ponding depth while for light irrigated crops it is on the basis of water storage in the root zone. The allowable depletion of soil water storage is limited by readily available soil moisture capacity. Response to rainfall for paddy depends on adopted ponding depth while for light irrigated crops it depends on the depletion level of readily available soil water from the root zone. The mode of irrigation supplies differ during various stages of crop growth and development, as water requirements of crops vary at different stages of crop growth and development.

### *Precision land leveling*

Declining irrigation water availability, sustainable crop production in increasing food demand necessitates quick adoption of modern scientific technologies for efficient water management. Land leveling at farmers field is an important process in the preparation of land. It enables efficient water utilization of scarce water resources through elimination of unnecessary depression and elevated contours. Laser leveling is laser guided precision leveling technique used for achieving very fine leveling with desired grade on agriculture field. It is becoming popular in almost entirely state of Punjab. Precision land leveling must be treated as a precursor technology for improving crop yields, enhancing input-use efficiency and ensuring long term sustainability of the resources base in intensively cultivated areas. Keeping in view the benefits of laser leveling, a study was conducted to evaluate the performance laser leveler at farmers' field and to estimate the saving in water resources at different level of adoption. Water saving in different crops at different level of laser leveler is presented in Table 8.

### *Ground water recharge*

Ground water played a major role in the success of green revolution and contributes to 60% of the total irrigated area of the country. Over exploitation of groundwater has reached critical level in Haryana, Punjab, Rajasthan and Tamil Nadu. The Punjab-Haryana region could lose its production potential in a few decades if current pattern of groundwater extraction and pollution, soil salinization and rice wheat cropping system persists. Necessary steps must be taken immediately for groundwater recharge in these areas. Rainwater harvesting has considerable potential for recharging depleted groundwater aquifers meeting irrigation demand.

**Table 8.** Water saving in different crops at different level of laser leveller

| Crop | Water saved (%) | Water required (cm) | Water saved (cm) | Area (ha) | Water saved (ha-m) at different level of irrigation | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 10 | 25 | 50 | 75 | 100 |
| Maize | 27.1 | 35 | 9.5 | 152560 | 1447 | 3618 | 7235 | 10853 | 14470 |
| Wheat | 26.0 | 35 | 9.1 | 3469520 | 31573 | 78932 | 157863 | 236795 | 315726 |
| Cotton | 27.25 | 20 | 5.5 | 541060 | 2949 | 7372 | 14744 | 22116 | 29488 |
| Paddy | 26.33 | 160 | 42.1 | 2625204 | 110595 | 276486 | 552973 | 829459 | 1105946 |
| Total | 26.25 | 81.3 | 21.3 | 6788344 | 146563 | 366408 | 732816 | 1099224 | 1465631 |

*Source:* Annual Report of All India Coordinated Research Project on Water Management, 2009-10

If water cannot be stored above the ground, it should be stored underground via artificial groundwater recharge. Considering that 98% of earth's freshwater resources are stored in underground there is enough space for more storage. Artificial recharge is achieved by putting water on the land surface and where it infiltrates into the soil and moves downward to underlying groundwater (Bouwer, 1999). Such systems require permeable soils (preferably sands and gravels) and unconfined aquifers with freely moving groundwater tables. Infiltration rates in such soils may typically range from 0.5 to 3 m/day during flooding. With continued flooding, however, suspended particles accumulate on the surface to form a clogging layer that retards the infiltration rates. Thus infiltration system must be periodically repaired to allow drying, cracking and if required mechanical removal of the clogging layer. Taking drying periods into account, long term infiltration rates for the year round operation of surface recharge systems may be in the range of 100-400 m per year (Bouwer, 2000).

Since sand and gravel soils are not always available, less permeable soils like sandy loam, loamy sand and light loams are increasingly used for artificial recharge systems. Such systems may have infiltration rates of only 30-60 meter per year, for year round operation. Systems in finer textured soils also require more land for infiltration basin. However in such systems environmental and recreational amenities can be attached. Where sufficiently permeable soils are not available or surface soils are contaminated, artificial recharge can be achieved by recharge pits or shafts (Bouwer, 1999). In confined aquifers, artificial recharge can be achieved by drilling injection wells drilled into the aquifer. The cost of such recharge is often much higher than the cost of infiltration with basins because wells can be expensive and water must be first treated to remove all suspended solids, nutrients and organic carbon to avoid clogging of the well-aquifer interface (Bouwer, 1997). Since such clogging is difficult to remove, prevention of clogging by pre-treatment and frequent pumping of the well is recommended. Recharge wells can be used for dual purpose i.e. recharge when water demands are low and abstraction where water demands are high.

The big advantage of underground storage is that there is no loss due to evaporation. Groundwater recharge systems are sustainable, economical and do not possess environmental problems. As underground formations act like natural filters, recharge system can be used to clean poor quality water. The artificial recharge structures, which are feasible in varied hydro-geological situations are described as follows:

### *Conjunctive use of surface and ground water*

Conjunctive use of multiple water resources should be practiced to mitigate the effect of the shortage in canal water supplies often subject to steep variations in river flow during different periods in the year; increase the dependability of existing water supplies; alleviate the problems of high water table and salinity resulting from introduction of canal irrigation; to facilitate the use of high salinity ground waters which, otherwise, cannot be used without appropriate dilution. Strengthening of knowledge based on geology and aquifer characteristics, hydrology of surface and groundwater facilities is required to develop appropriate conjunctive use system.

## Management of Poor Quality Groundwater

Groundwater in arid regions is largely saline & in semi-arid it is sodic in nature. Indiscriminate use of poor quality water for irrigation deteriorates productivity of soils through salinity, sodicity and toxic effects. In addition to reduced productivity, it deteriorates the quality of produce & also limits the choice of cultivable crops. In saline groundwater areas, where canal water is available in limited quantities, conjunctive use of canal water and saline groundwater is recommended. Dilution or mining of available poor quality water with good water should be done in such proportion that resultant EC is acceptable for the range of crops to be grown in a given area. Some of the management options to manage the saline groundwater are selection of semi tolerant crops, salinity tolerant cultivars, proper selection of crop sequences, avoiding saline water use during initial growth stages, addition of farm yard manure, organic matter, application of additional dose of nitrogen etc. some important points should be noted for management of conjunctive use practices are analysis of saline water to evaluate its use potential, selection of crops/varieties, pre sowing irrigation with good quality water so that germination & seedling emergence is not affected, adequate leaching of salts, change of cropped area & adoption of improved cultural & nutrient management practices.

Management technology options for use of sodic groundwater includes selection of crops, appropriate irrigation scheduling and conjunctive use options with canal water, river water management & leaching strategies to maintain a high level of soil moisture & low level of salts & exchangeable sodium in the rhizosphere, use of land management practices to increase the uniformity of water distribution, infiltration and salt leaching besides the optimal use of chemical amendments like agricultural grade gypsum and acidic pyrites at proper time & mode of their application with judicious use of organic materials & chemical fertilizers.

### *Mitigating groundwater pollution*

The choice of appropriate cropping systems and management practices help in minimising nitrate leaching besides improving N-use efficiency. Legume intercropping in cereals grown with wider row spacing has also been reported to reduce nitrate leaching. Parallel multiple cropping (a system of growing two dissimilar growth habit crops with minimum competition) of sugarcane and black gram and that of pigeon pea and maize resulted in low $NO_3$-N content in soil profile as compared to sole cropping. As a crop management strategy for minimizing $NO_3$-N leaching, delaying large N applications until the crop can utilise it, avoiding irrigation when large amounts of $NO_3$-N present in the root zone and split application etc has also been recommended.

There is a specific need to create awareness among people about the presence of fluoride in ground water, its action on body tissues and available remedial technologies. Various artificial recharge techniques including Aquifer Storage Recovery (ASR) technique may be applied to improve the quality of water by dilution. The ASR technique is being followed in many parts of the world and has proved to be a viable or cost-effective option for storing large volumes of fresh water. Looking at the success achieved through ASR in many countries, there is a case to plan trial of this technology at suitable locations in the country. Besides this, the concept of mixing two different aquifers/sources of water can also be tried to overcome the fluoride problem (Bajwa *et al*., 1993).

Investigations of geochemistry are very essential to understand the occurrence and mobilization of arsenic in the aquifer system. Thus, there is urgency for an integrated study on geological, hydrological and geochemical characteristics of the multi-level aquifer system to predict the origin, occurrence and mobility of arsenic in ground water. There is a priority to arrive at suitable and economically viable alternatives to maintain sustainable drinking water supply. The traditional system of using surface run-off water can be augmented by system to reduce dependence on ground water extraction.

### *Farmers' participation in irrigation water management*

The effective water management is critically linked with the performance of local level water institutions. The innovation of WUA/*Pani Panchayat* institution has diverted larger flow of information as well as initiative from government irrigation departments towards it. Transfer of irrigation management responsibility from the government irrigation authority to local management demands both allocative and investment decisions by the farmers' group / organization. It needs to understand that the problem at main system level is mainly a problem of allocation, of rights and entitlements and therefore of governance. There has to be a paradigm shift giving the irrigators (farmers) real decision-making power in managing the irrigation system as a whole system. Watershed management is by nature beyond the work of individuals and thus collective effort by all farmers concerned is required for successful management. Replication of successful samples and community led success stories are likely to lead to most sustainable results. The objectives of farmers' groups cannot be realized overnight and it takes time. Therefore, it is of paramount importance to keep it functional and effective for a long time. It should become a part of the tradition of the village over time, as is the case with the already existing traditional village organizations.

### *Water management in waterlogged areas*

The saucer shaped land forms, high rainfall (average 1500 mm) due to southwest monsoon (June–September), poor drainage condition slow disposal of accumulated water in the plains to the ocean make the coastal region susceptible to waterlogging and flood prone and area remains submerged for about 5-6 months (July – November) under water depths varying from 0.75-2.0 m. On the other hand, the winter and summer rainfall (November-May) is meagre and erratic. As a result, after December, the land becomes dry and available soil moisture in the land is not sufficient to meet evapo-transpiration loss of any crops. Thus, coastal waterlogged areas are subjected to receive both extreme events. In one season the area is under productive due to excess water, in other season agriculture is not possible because of lack of soil moisture. Due to constant water logging of 0.5 to2.0 m depths, the normal rice fails to grow in seasonal flood prone areas. Improved deep waterlogging rice cultivars like 'Hangseswari', 'Saraswati' were introduced with improved sowing methods (line sowing with 20 cm distance, row to row and fertilizer dose of 20:20:20) in the seasonal waterlogged areas. (Kar *et al*., 2010). These varieties can produce up to 2.8 t ha$^{1}$ grain yield in *kharif* season in deep waterlogged situation if flood commences after second weeks of August.

The suitable water harvesting structure depending upon the maximum depth of waterlogging was designed and constructed by taking 25-30% of the total field of a farmer in representative waterlogging areas of Puri district. Waterlogging tolerant rice varieties were grown surrounding the structure during kharif season. The water inside the structure was utilized for fish rearing and the bund was utilized to grow vegetable short duration fruit and vegetable crops initially and to grow firewood plants at later stages. The harvested was also utilized to grow high yielding medium duration rice (cv. 'Lalat', 'Konark') and vegetable crops during Rabi season, through this approach farm returns enhanced up to about 1.0 lakh per hectare from the waterlogged area which remained unproductive earlier. The cropping intensity of farmers was increased with the range between 150-250%. The aquatic like water chestnut, medicinal plant (*Arocas Calamas*) was introduced in seasonal flood prone areas and package of practices for their cultivation were standardized. From water chestnut and *Calamas cultivars* Rs. 19,000/ha and Rs. 35,000/ha net returns respectively were obtained.

## Conclusions

Water forms the backbone for all the future endeavors to achieve the vision of food security. In the present data context, up calling agricultural economic growth to more than 4% annually is the main challenge. Taking water technologies for better water management from lab to land is a formidable task to be addressed. Modernization/automation of irrigation systems, precision irrigation, land reforms, corporate farming, cooperative farming, water and energy pricing, crop insurance, institutional mechanism for better governance, water rights are some of the key issues for better water management in agriculture. These have direct role in climate change mitigation and adaptation. The projected food requirement demands a pronounced role for research, development and training in the water and agriculture sector.

It is evident that the water availability for agriculture is declining and to enhance agricultural production more water is needed. Therefore, concerted and holistic efforts are required in increasing the overall water use efficiency at system level which would be achieved through various measures like timely execution of projects, minimizing the losses, better operational efficiency through stake holders participation, implementation of on–farm water management technologies, conjunctive use of water and changes in irrigation policy. Simultaneously, the effort of R & D institutions are required in development of water management technologies, suitable database development, economic studies of various irrigation systems, policy guidelines for on farm water management and adoption of participatory irrigation management. Serious efforts from developmental agencies as well as research institutes are required to develop a suitable water perspective plan for various regions in the country for its implementation.

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# Climate Change Adaptation in Rainfed Agriculture: Challenges, Initiatives and Strategies

**Vinod Kumar Singh**

*ICAR-Central Research Institute for Dryland Agriculture, Hyderabad-500059*
*Email: director.crida@icar.gov.in*

## Introduction

Rainfed agriculture accounts to about 52% net sown area in India and is crucial to country's economy and food security since it contributes to about 40% of the total food grain production (85% of coarse cereals, 83% of pulses and 70.5% of oilseeds). It also supports two-thirds of livestock and 40 % of human population and influences livelihood of 80% of small and marginal farmers. Even if full irrigation potential is created, still 40% of net cultivated area will remain as rainfed agriculture which would continue to be a major food grain production domain (CRIDA Vision, 2050). The climate change impacts are evident on agricultural production and productivity in general and rainfed agriculture in particular. Climate change, which is expected to manifest as increased frequency and intensity of extreme climate events including droughts (IPCC, 2015), is particularly of concern in drylands where species and communities already have to cope with dramatic variations in temperature and droughts (UNCCD, 2017). In India, the estimated countrywide agricultural production loss in 2030 will be over $7 billion that will severely affect the income of 10% of the population. However, this could be reduced by 80%, if cost-effective climate resilience measures are implemented (ECA, 2009).

## Climate Change Adaptation in Rainfed Agriculture: Key Challenges

*a. Climate change/variability impacts:* In India, the amount and distribution of rainfall during south west monsoon is the key for success of agricultural production in rainfed areas. The rainfed areas experience 3-4 drought years in every 10-year period, of these 2 -3 are in moderate and 1 may be of severe intensity. A decrease of one standard deviation from the mean annual rainfall often leads to a complete loss of the crop. Dry spells of 2 to 4 weeks during critical crop growing stages cause partial or complete crop failure (Rockstorm and Falkenmark, 2000). A district level climatic analysis in the country revealed spatial shifts of climate zones in about 27% of the geographical area in the country i.e. a substantial increase of arid region in Gujarat, a decrease of arid region in Haryana, and increase in semi-arid region in Madhya Pradesh, Tamil Nadu and Uttar Pradesh due to shift of climate from dry sub-humid to semi-arid. Likewise, the moist sub-humid pockets in Chhattisgarh, Orissa, Jharkhand, Madhya Pradesh and Maharashtra states shifted to dry sub-humid to a larger extent (Raju *et al.,* 2013). These climate shifts in rainfed areas will have larger implications for crop planning, water resources assessment and prioritizing drought proofing programmes. The Coupled Model Inter comparison Project Phase 5 (CMIP5) based model ensemble, based on new-emission scenarios termed as Representative Concentration Pathways (RCPs), projects a warming of 1.5, 2.4, 2.8 and 4.3°C for India under the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenarios, respectively, for

2080s (2071-2100) compared to the baseline period of 1961-1990 (Chaturvedi *et al.,* 2012). The CMIP5 based ensemble projects an all-India precipitation increase of 6, 10, 9, and 14% increase under the RCP2.6, RCP4.5, RCP6.0 and RCP8.5 scenarios, respectively, for 2080s compared to the 1961-1990 baseline. A consistent increase in seasonal mean rainfall during the summer monsoon periods has been projected. Rainfall is likely to decline by 5 to 10% over southern parts of India, whereas 10 to 20% increase is likely over other regions. There is a probable decrease in the number of rainy days over major parts of the country pointing at likely increase of extreme events. The recent ensemble models project that the frequency of extreme precipitation days (>40mm/day) are likely to increase. Rainfed crops are likely to be worst hit by climate change because of the limited options for coping with variability of rainfall and temperature. Climatic risks like droughts, unseasonal high intensity rainfall events, and floods, poor water and nutrient retention capacity of soil and low soil organic matter (SOM) impact rainfed agriculture highly vulnerable, requiring a different outlook and strategy. In the recent past, continuous high rainfall in a short span leading to water logging and heavy rainfall coupled with high speed winds are being experienced at various growth stages of rainfed crops leading to serious crops losses, outbreak of pests and diseases and sometimes total crop failure.

*b. Resource poor operational land resource base:* About 58.14 Million operational land holdings are totally unirrigated, out of which 85 % account to marginal and small operational holdings i.e. 37.06 m marginal and 11.69 m small (DES, 2011). These holdings are poor in soil quality and other land characteristics. Therefore, the challenge lies in sustaining these holdings in respect of stabilizing productivity and profitability at the backdrop of the impacting climate change/variability.

*c. Bridging yield gaps:* Though, yield gain i.e. more than one ton/ha is witnessed in some rainfed crops, yet large yield gaps remain in several rained crops and regions between yields obtained at research stations and on farmers' fields. In chronic drought prone areas, the yield gaps will continue to remain large, both due to non-adoption of technologies and non-availability of tailor-made agro-ecology specific package of practices.

*d. Enhancing water productivity:* Rainwater availability and its efficient utilization determines the success of rainfed agriculture. A 4°C rise in temperature and a 10% decrease in rainfall is expected to reduce the stream-flow by 33% in mean annual, 15% in pre-monsoon, 35% in monsoon, 32% in post-monsoon and 21% in winter seasons. The National Water Mission, institutionalized under the National Action Plan for Climate Change, has set the target to improve the efficiency of water use by at least 20%. In a given land use setting, climatic variables especially temperature and rainfall regulate the irrigation water demand. At present in India, blue and green water availability is above the 1,300$m^3$/capita/year threshold. However, with climate change, blue-green water availability is estimated to decrease to less than 1,300$m^3$/capita/year, implying that by 2050, all of India could be exposed to water stress.

*e. Maintaining soil health and productivity:* The spatial variability of soils in rained agroecosystems typically associated with Entisols, Inceptisols, Alfisols, Vertisols and Aridisols. The major soil constraints that are limiting productivity of rainfed crops are shallow depth, low plant available water capacity (PAWC), sub-soil hard pans, very low subsoil saturated hydraulic conductivity, imperfect soil/land drainage, sub-soil gravelliness, calcareousness, low soil organic carbon, multiple nutrient deficiencies etc. Soils and soil water will be adversely affected by climate change and this in turn will lead to reduction in yield of many crops. The risk of increased erosion is imminent in soils of dry agro ecosystems. High and extreme precipitation will increase runoff primarily due to the inability of the soils to absorb and hold water. Extended dry periods will reduce vegetation cover which again will result in substantial runoff. Such erosion events occurring frequently will lead to ecosystem change and also loss of soil nutrients. In addition, aridity can hinder surface decomposition and nutrient recycling, thereby affecting crop productivity. Presently, on an average, the soil organic carbon is 5g/kg in soils in rainfed areas whereas the desired level is 11 g/kg. Changes in soil carbon status is also a matter of concern under changing temperature and changing rainfall regimes, soil carbon not only is important for growth and development of the crop but also for retention of water and nutrients and as an energy source for decomposition process in the soil. The sustainable management of soil physical environment has a significant role in water and nutrient uptake and losses, pollutant transport and also emission of greenhouse gases from soil. In rained agriculture, managing optimum soil physical environment are essential not only for sustainable management of soil and water resources but also for realizing yield potential of crops.

*f. Low and skewed farm mechanization*: Farm mechanization in rainfed areas is very low due to small and marginal holdings, resource poor farmers etc. In view of the short window for sowing of rainfed crops and also for moisture availability period, farm mechanization in small farm holdings is very crucial in timely and precision agricultural operations and in large areas.

## Climate Change Adaptation in Rainfed Agriculture: Major National Initiatives

The major initiatives launched in the domain of climate change research and climate resilient agriculture are:

*a. Network Project on Climate Change (NPCC)*: In 2004, the Indian Council of Agriculture Research (ICAR) launched NPCC with the objectives of quantifying the sensitivities of food production systems to different scenarios of climate change, adaptation and mitigation strategies in agro-ecosystems and to provide policy support. The important outputs related to rainfed agriculture from NPCC indicated increased emphasis on soil conservation in peninsular and central India because of projected high run-off and soil losses due to changes in rainfall, and emphasis on agro-forestry systems in sub-tropical climates for maximum carbon sequestration potential (Naresh Kumar *et al*., 2012)

*b. National Mission for Sustainable Agriculture (NMSA*): The National Mission for Sustainable Agriculture (NMSA), one of the eight missions of National Action Plan on Climate Change (NAPCC). NMSA was formulated in 2010 to represent multi-pronged, long term and integrated strategies for addressing climate change impacts; aimed at devising strategies to make Indian agriculture more resilient to climate change and to promote sustainable agriculture through a series of adaptation measures focusing on ten key dimensions encompassing Indian agriculture viz. improved crop seeds, livestock and fish cultures, water use efficiency, pest management, improved farm practices, nutrient management, agricultural insurance, credit support, markets, access to information and livelihood diversification. Subsequently, these measures had been embedded and mainstreamed into various Missions/Programmes/Schemes of Ministry of Agriculture & Farmers Welfare, Government of India with a special emphasis on soil & water conservation, water use efficiency, soil health management and rainfed area development.

c. *National Initiative on Climate Resilient Agriculture (NICRA*) : The ICAR in 2011 launched the flagship project on National Initiative on Climate Resilient Agriculture (now called National Innovations in Climate Resilient Agriculture) with the objectives to undertake strategic research on adaptation and mitigation; to validate and demonstrate climate resilient technologies on farmers' fields; to strengthen the capacity of the stakeholders in climate resilient agriculture and to draw policy guidelines. The major components under NICRA are: a) strategic research b) Technology demonstration component, and c) capacity building of stakeholders.

## Climate Change Adaptation in Rainfed Agriculture: Key Strategies

According to IPCC (2001) adaptation as refers to "*adjustments in ecological, social or economic systems in response to actual or expected stimuli and their effects or impacts. This term refers to change in process, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change"*. Adaptation hence involves adjustments to decrease the vulnerability of communities, regions, and nations to climate variability and change and in promoting sustainable development. Recent debates focusing on the relationship between climate change stimuli and adaptation in agriculture recognize that climate change includes not only long term changes in mean conditions, but also a change in the year-to-year variation in growing season conditions, and the frequency and magnitude of extreme weather events. Depending on its timing, goal and motive of its implementation adaptation can either be reactive or anticipatory, private or public, planned or autonomous. Adaptation can also be short /long term localized or widespread (Ravindra Chary *et al.*, 2013). Adaptive responses are mainly related to technological interventions, management practices and policy planning. In agriculture the main method to tackle climate change related effects is by adaptation.

Some of the key strategies for climate change adaptation in rainfed agriculture are suggested below:

*a. Delineation of Climate change Vulnerability at sub-district level:* District level vulnerability atlas has been revised in 2020 by adopting IPCC AR 5 Report as risk assessment of Indian agriculture to climate change (Rama Rao *et al.*, 2019). The identification of very high risk and high risk districts guided NICRA TDC programmes and many other climate research/policy programmes by national institutes, ministries/departments, state governments and non-government organizations. However, delineation of climate risk *hot spots, particularly drought* at sub-district level is very much needed using advanced geospatial technologies (hyperspectral and drone remote sensing, GIS etc.).

b. *Drought forecasting, monitoring and management:* Since drought is the manifestation of rainfall deficiency on a large scale, any forecasting technique should indicate rainfall amounts, particularly on a long-range basis, which is adequate to give an idea of impending drought. Drought prediction in advance would help taking water, soil and crop management and other policy decisions. Drought assessment and monitoring at different scales and timely dissemination of information constitute vital part of drought management system. Appropriate mechanism, reliable data, standard procedures for indices of drought prevalence and intensity are prerequisite for developing efficient drought management strategies. Identification and development of drought threshold indices for various activities like agriculture, water resources, energy, etc. are important to formulate and initiate drought management strategy approaches for a given region. For this purpose, monitoring soil moisture status, water availability indices, current crop status and irrigation needs to complete the crop growth cycle, current water status in reservoirs, lakes, irrigation wells, etc. are of great importance. Besides these, monitoring present synoptic conditions, viz., break monsoon condition; the position of monsoon trough, occurrence of low-pressure systems, their intensification and subsequent movement are also essential. Monitoring of these indices need to be carried out at least weekly during the cropping season. This information when coupled with the climate of a region, i.e., information of the region regarding its drought proneness and the pattern of drought incidence and spread, will enable drought prognostication with higher degree of confidence.

*c. Refining soil conservation and rainwater management technologies:* The soil physical environment in rainfed production systems can be improved through a) building *in situ* moisture reserves to tide over the recurring drought spells and b) preventing loss of stored soil moisture. Many agroecology-specific rainwater management technologies are being developed by CRIDA-AICRPDA (All India Coordinated Research Project for Dryland Agriculture) and National Agriculture Research system. Rainwater management technologies demonstrated in AICRPDA and NICRA adopted villages helped to enhance cropping intensity up to 140%. However, inter-annual and intra-seasonal rainfall variability i.e. high intensity rainfall events are being experienced in rainfed regions which necessitates revisiting the design/dimensions of the present *in situ* moisture conservation measures and rainwater harvesting structures using SWAT modelling, GIS etc. (Rejani *et al*., 2020).

*d. Developing conservation agriculture strategies in rainfed production systems:* Developing sustainable conservation agriculture (CA) strategies in crop-tree- animal systems in rainfed agroecologies is needed for resource conservation amidst growing concerns of resource degradation, decline in soil quality, low factor productivity and climate change. Site specific and production system specific development of CA practices and their scaling up is an emerging opportunity for efficient conservation of resources and enhancing the productivity in the years to come. Some key challenges of CA in rainfed agriculture include development, standardization of management practices, particularly *in situ* moisture conservation, seeding and harvesting devices with minimal soil disturbance and with residues on soil surface and effective control of weeds for important rainfed production systems.

*e. Real Time Contingency Planning (RTCP) implementation to manage weather aberrations:* CRIDA led in preparation of District Agriculture Contingency Plans (DACPs) for 650 districts in the country. Each DACP provides information on contingency measures to cope with delayed onset of monsoon, drought, flood, high intensity rainfall events, frost, heatwave, cold wave and cyclones in field crops, horticulture crops, and the coping measures were suggested to address before, during and after occurrence of extreme weather events in livestock, fisheries and poultry sectors. The farming situation-wise contingency measures are suggested to cope with delayed onset of monsoon (2,4,6, and 8 weeks delay) and early, mid-season and terminal drought (Venkateswarlu *et al*., 2011). The challenge has been to operationalize DACPs at sub-district level. Real Time Contingency Planning (RTCP) is conceptualized in AICRPDA as "any contingency measure, either technology related (land, soil, water, crop) or institutional and policy based, which is implemented based on real time weather pattern (including extreme events) in any crop growing season" (Srinivas Rao *et al*., 2016) and being implemented under NICRA in 54 villages in 14 states in diverse rainfed agroecologies as a two pronged approach, i.e. i) preparedness, and ii) implementing contingency measures on real-time basis. The RTCP aims first to establish a crop with optimum plant population during the delayed onset of monsoon, to ensure better performance of crops during seasonal drought and extreme events, enhance performance, improve productivity and income, and to enhance the adaptive capacity of the small and marginal farmers. The preparedness emphasizes on a combination of tolerant variety/ cropping system, rainwater/soil/crop/nutrient management practices along with timely availability of inputs while real-time basis implementation focus on the crop/soil/moisture /nutrient management measures to cope with delayed onset of monsoon, seasonal drought, floods and other extreme events. The experiences of RTCP implementation indicated many opportunities for developing adaptation strategies both as preparedness and real-time response with NRM, crop, fodder, animal based interventions, most importantly establishing Custom hiring centres which enabled timely and precision agricultural operations.

f. *Scientific Land Use Planning for building resilience at agriculture landscape level*: Delineation of Soil Conservation Units (SQUs), Soil Quality Units (SQUs) and Land Management Units (LMUs) from the detailed soil resource information at cadastral level in a microwatershed would help in land resource management. A resilient, less risk prone farming system based on the land requirements and farmers' capacities is to be developed for climate adaptation and also to address the unabated land degradation. SCUs are basically for soil and water conservation prioritized activities to mitigate drought while SQUs are to address soil resilience and to improve soil organic carbon, problem soils amelioration and wastelands treatment. SCUs and SQUs are merged in GIS environment to delineate land parcels in to homogenous Land Management Units with farm boundaries. LMUs would be operational zed at farm level for taking decisions on arable, non-arable and common lands for cropping, agroforstry, agrihorticulture, etc., and further, for levying the most fragile land parcels for ecorestoration. Rainfed land use planning modules should be based on these units for risk minimization, enhanced land productivity and income, finally for drought proofing (Ravindra Chary *et al*., 2015).The experience of LMU approach adopted in Kavalagi micro-watershed, Karnataka adopted by AICPDA indicated the yield variability with the same varieties of chickpea (cv. JG-11) and *rabi* sorghum (cv.BJV-44 and cv.M-35-1 in different LMUs wherein the seasonal rainfall varied and was deficit up to 30% compared to normal seasonal rainfall. Though, the rainfall was the same for entire watershed in 3 seasons, the yield of crops varied due to spatial variability in characteristics of LMUs. The yield of both chickpea and sorghum was higher on LMU-I >LMU-III>LMU-V>LMU-VII due to limitations in soil physical and chemical characteristics with LMU-I having more favourable land characteristics for crop growth (AICRPDA-NICRA Annual Report, 2019-20). The results revealed that the performance of crops vary due to spatial variability in land and soil characteristics in a landscape though the rainfall is uniform. Therefore, it is emphasized that building resilience of agriculture to be achieved at landscape level with suitable cropping in a favourable land and soil environment.

*g. Smart farming in rainfed production systems*: There is a need for real-time soil moisture monitoring based precision protective/supplemental irrigation to rainfed crops from the stored rainwater. Research in future should focus on using Wireless Sensor Network, IoT (Internet of things) and AI (artificial intelligence) based technologies for higher water productivity in rainfed production systems. In data-driven smart farming, big data access, availability of quality data, big spatial data computation, spatial data integration, data privacy and rights to use data are some of the important challenges (Obi Reddy *et al*., 2021). Use of AI with computer vision and robotics is able to build next-generation agriculture equipment, which can detect stresses in crops, assess nutrient deficiencies in soil, reduce chemical application etc. There also exists a lot of scope for smart mechanization for various agricultural operations to achieve higher energy use efficiency in rainfed agriculture. *Smart farming powered by trending technologies like AI with big data analytics, IoT and ML (Machine learning) immensely helps in developing reliable w*eather – based information system and dissemination of real-time agromet advisories at large scale.

*h. Ecosystem services*: Many soil, water and crop management based interventions produce a variety of ecosystem services, such as regulation of soil and water conservation, carbon sequestration, support for biodiversity, increased productivity, improved soil quality, improved environmental quality, nutrient cycling, hydrological services etc. In the face of climate change, it is pertinent to develop ecosystem service indicators for assessing and quantifying the benefits of climate adaptation practices in rainfed production systems.

## Conclusions

Climate change is evident and impacting Indian agriculture. In the face of climate change, many challenges are posed for adaptation in rainfed production systems. Many initiatives such as NPCC, NMSA and NICRA have been taken at national level to address these challenges in rainfed agriculture. Since drought occurrence is not sudden, its adaptation can be planned properly. With the available knowledge and gradually emerging tools and techniques, the effects of droughts can largely be counteracted in many situations, if not eliminated completely. Technological interventions as adaptation strategies play a greater role in drought proofing and other extreme events such as unseasonal high intensity rainfall events in rainfed agriculture. The productivity of rainfed crops can be enhanced significantly on a sustainable basis, provided the two basic natural resources soil and rainwater are well managed. These practices insulate crops against the mild stress and increase crop yields. Sustainable soil and land management practices is necessary to build resilience at landscape level. Climate change adaptation must be viewed as a dynamic process requiring a continued attention.

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# Equity Empowerment in Agriculture through Science and Technology

**Debapriya Dutta**

*Head, SEED-SSTP and NRDMS Division*
*Department of Science and Technology, Government of India, New Delhi*
*Email: ddutta@nic.in*

## Introduction

Global agriculture and food system is in a transition today. Despite improvement in agricultural productivity, global economic growth and a reduction in poverty over the last 30 years, about 2.1 billion people are still living in poverty, with 700 million in extreme poverty. Distress migration is at levels unprecedented for more than 70 years as the social cohesion and cultural traditions of rural populations are threatened by a combination of limited access to land and resources and rising numbers of crises, conflicts and disasters, many as a consequence of climate change. Such inequality is hindering equable progress of the civilization. Even in countries where poverty has been reduced, pervasive inequalities remain between rural and urban areas, between regions, between ethnic groups, and between men and women. Most of the world's poor and hungry are rural people who rely on agriculture for their livelihoods, and the high share of their expenditure on food in their household budgets, make agriculture the key to poverty and hunger alleviation. Agriculture plays an important role in pro-poor growth (FAO, 2017).

As the prime connection between people and the planet, Sustainable Food and Agricultural (SFA) system is at the core for attaining Sustainable Development Goals (SDGs) by 2030, addressing mainly the SDGs 1 (End of Poverty), 2 (End Hunger), 3 (Ensure healthy lives), 5 (Achieve Gender equality and empower all women and girls), 8 (Promote sustained, inclusive and sustainable economic growth) and 10 (Reduce inequality within and among countries). FAO has developed five principles of SFA that balance the social, economic and environmental dimensions of sustainability viz. Increase productivity, employment and value addition in food systems; protect and enhance natural resources; improve livelihoods and foster inclusive economic growth; enhance the resilience of people, communities and ecosystems and adapt governance to new challenges ( FAO, 2018).

## Equity in Agriculture: Challenges

Though the context and history of social, racial, and gender discrimination are unique to each country, common shared themes include the treatment of farm and food system workers, gender discrimination, access to land and agricultural financing.

Family or small farming constituting about 88% of the global farms generates 80% of the global food. However, the smallholder family farmers suffer from low productivity due to lack of access to resources, technologies and services. Thus, forcing them into vicious cycle of poverty and making them vulnerable to any natural, man-made and financial aberrations. In India, 70% of its rural households still depend primarily on agriculture for their livelihood, while 82% of farmers being small and marginal. However, they contribute to only 17–18% of the GDP.

Across developed markets, agricultural landowners have benefited by exploiting farm workers, keeping minority and previously excluded groups from accessing land and agricultural financing, from healthy food access, and polluting the water and air in rural communities. There is requirement of improved equity, justice, well-being, and dignity for farm workers and tenant farmers in the food and agricultural supply value chain (FAO, 2018).

Women produce over 50% of the world's food (FAO, 2011) and comprise about 43% of the agricultural labour force, both globally and in developing countries (Doss, 2014).

Women and girls make almost half of the agricultural workforce in developing countries, and that workforce is typically large. For example, Indian Agriculture employs 80% of all economically active women, 33% of them are agriculture labour and 48% of the self-employed farmers. However, only about 13% of them own land. Yet women in agriculture face a variety of obstacles viz. lack of access to training, machinery, and new technology. In highly unequal countries, the majority of the farming population, particularly women, lacks the economic resources and capacity to invest in appropriate agricultural technologies, as well as the knowledge to implement improved agricultural practices. Because of the disparity in access, women farmers face an increasing knowledge gap.

As these inequities are spread systematically throughout the food system, solutions must be oriented toward a new economy and for environmental justice, labour rights, immigration rights, food justice, climate justice, and human rights (Elsheikh, 2016).

## Empowerment for Equity in Agriculture: Solutions

### *Access to productive resources, finance and services to small and marginal farmers*

Smallholder farming can be leveraged to eliminate poverty. The approaches/processes should address the systemic barriers in smallholder farming for improving its efficiency. Initiatives to promote smallholder farming are generally targeted towards improving productivity, incomes and a diversification in livelihoods. Enhancing productivity of small-scale farmers can be achieved by providing greater access to land, affordable quality seeds and planting materials of suitable crop varieties, services, finance, technologies and modern tools.


Contour mapping according to gradient Elevation based crop system

**Fig. 1**. Elevation based cropping system based on contour mapping gradient

In eastern UP, low lying areas suffer from persistent floods, which affect the agriculture system of marginal farmers. Digital elevation map of villages was developed and gradient of villages were comprehended by villagers. Accordingly, differential elevation base cropping system was introduced. As a result, soil erosion was reduced and soil moisture was resulting in improved productivity and doubling of income of small and marginal farmers. Also area was freed from waterlogging and was available for *Rabi* season crops on time,

### *Connecting smallholders to markets*

Reducing a community's reliance on distant markets, intermediaries and food price fluctuations can be met by decentralising access to resources, finance and technology.

Improved access for agricultural and food producers to markets with higher efficiency, transparency and competitiveness. In this context Information and Communication Technology (ICT) like mobile phone based apps mKrishi , agro advisory services like IKisan, Kisan Mitra, ICAR-KMAS etc. has created significant impact by relaying price information quickly, transparently and accurately, and to aid negotiation by bringing producers and traders together.

### *Knowledge capacity building in alignment with livelihood system*

Replacing Top-down and technology-oriented systems, integrated, market-oriented and farmer-driven technology capacity building system involving multi stakeholder is evolving world over. Smallholder family farmers, rural women and men, and their organizations are increasingly regarded as full partners in this process. Appreciating the fact that in predominant agricultural livelihood, workers from marginalized sections of the society mostly do the labour-intensive jobs, Science, Technology and Innovation (STI) hub for Scheduled Caste and Scheduled Tribe communities have been established by the Department of Science and Technology, Government of India to addresses the problems in their livelihood system. It is thus envisaged that establishment of Science Technology and Innovation (STI) Hubs will develop, nurture and ensure the development, improvement and delivery of appropriate and relevant S&T approaches for inclusive social and economic development of the Scheduled Caste and Scheduled Tribe population in the country. The STI Hubs follow a bottom up approach to identifying predominant livelihood system in the area of interest and identify the strongest and weakest links in the predominant livelihood systems for appropriate STI interventions and creation of social enterprises. The Indigenous Knowledge Systems of different communities are captured and improved with infusion of advanced technologies to improve the livelihood system efficiency (Fig. 2).

## Objectives of STI hub are:

1) To capture the weakest linkages in the predominant livelihood systems of the SC and ST communities and improving the livelihoods through Science and Technological interventions
2) To identify the strongest aspects in the livelihood system in respect of current occupations/livelihoods of the SC and ST Communities in the target area for establishing social enterprises, local manufacturing units and start-ups for boosting the rural/village economy
3) To harness, document, research, validate and conserve the Indigenous Knowledge Systems (IKS), skills and practices of different communities through inputs of Science and Technology to integrate IKS into appropriate technology, innovation and development for sustainable development practices in livelihood system

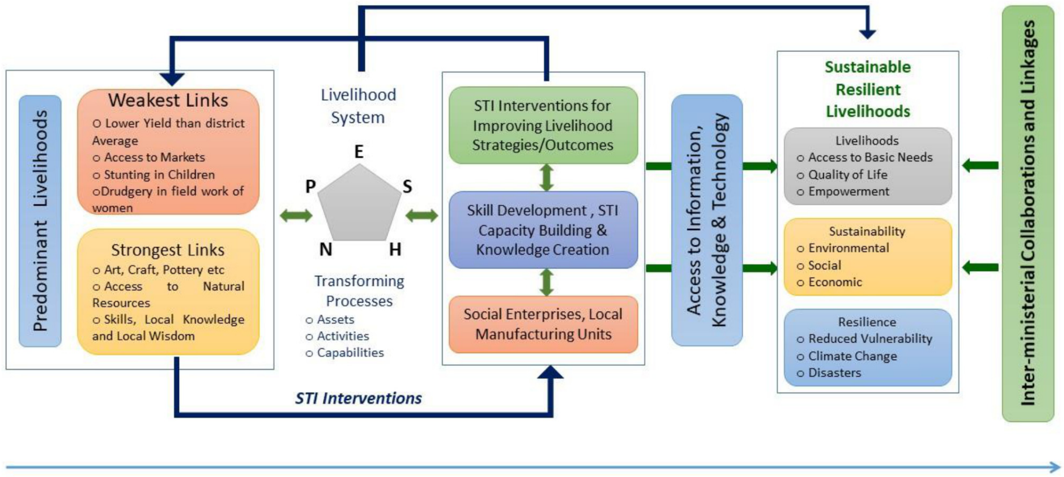


**Fig. 2.** Technology delivery platform for welfare system strengthening

## Women Empowerment for Gender Equity

Women's empowerment has a direct impact on agricultural productivity and household food security (Harper *et al.*, 2013; Sraboni *et al.*, 2014), and as a result it remains at the core of agricultural research and outreach practices in developing countries (Gates, 2014). Donor agencies, local governments and NGOs are increasingly targeting women as priority clients and strengthening their investments to empower women and reduce inequity between sexes (World Bank, 2012; Gates, 2014).

Addressing gender equity is essential to achieving sustainability in agriculture. High levels of inequity make it harder to increase productivity and reduce poverty and hunger. Countries where incomes are highly unequal have, on average, lower levels of land productivity and are more prone to food insecurity. These inequities are slowing many countries' progress toward Sustainable Development Goal 2 (SDG2) to "end hunger, achieve food security and improved nutrition and promote sustainable agriculture" by 2030.

In order to address Women Empowerment through Science and Technology, Department of Science and Technology. Government of India has established 45 Women Technology Parks (WTP) across the Nation (Fig. 3). WTPs act as a resource centre where all necessary support is made available to women from a single platform for providing training, capacity building in various technologies, providing livelihood opportunities and improving the quality of life of the women by reducing their drudgery, better resource management through value addition, etc.

## Objectives of WTPs are:

1) Development and adaptation of innovative technologies, transfer of proven technologies and demonstration of live technology models to address the weakest link and /or strongest link of the livelihood system of women, resulting in significant improvement in quality of life and/or income generation.
2) Skill development and capacity Building of women using science & technology preferably as per National Skill Qualification Framework (NSQF) for various sectors using area specific resources.

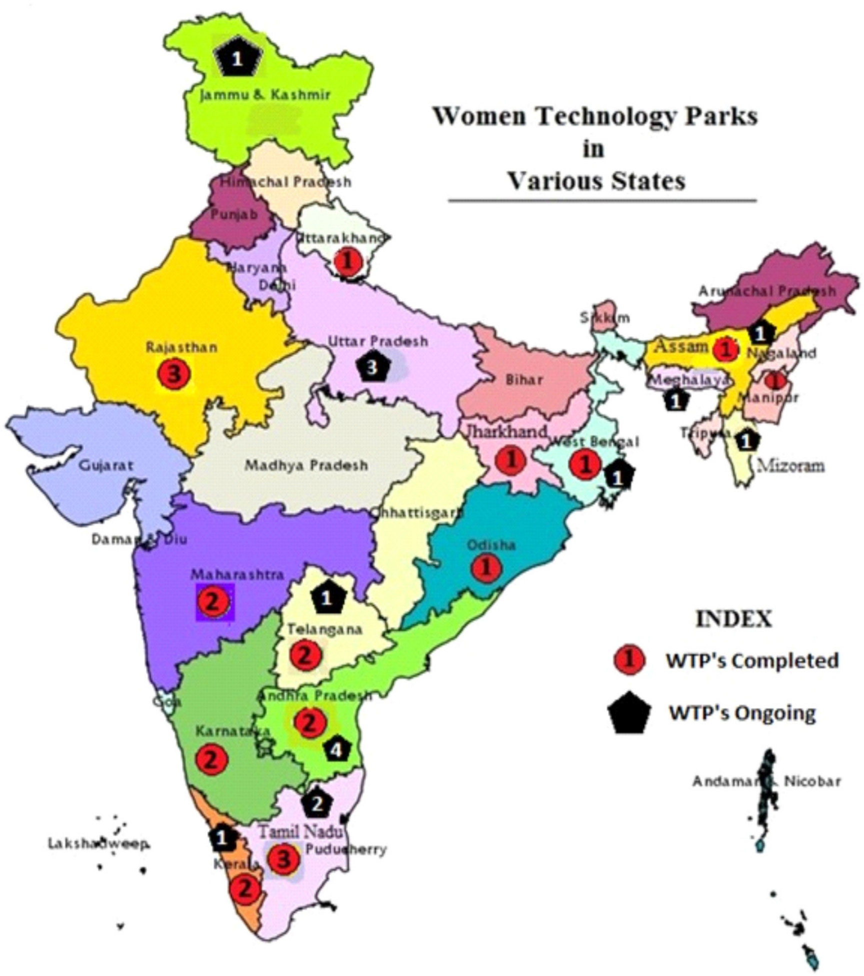


**Fig. 3.** Distribution of Women Technology Parks

## Conclusion

Knowledge creation, harnessing Technology and fostering Innovation are the three axes for accelerating global competitiveness and socio-economic transformation. In the context of Indian agriculture equity needs to be brought by empowering the marginal farmers, farm workers from disadvantaged communities and women. Science and Technology can play a yeomen role by knowledge enhancement, improving technology access and usage in alignment to the livelihood system requirement and advanced technology introduction at community level.

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# Sensors and Smart Agriculture

**P. Krishnan* and Monika Kundu**

*Division of Agricultural Physics, ICAR–IARI, New Delhi-110012*
**Email: prameelakrishnan@yahoo.com*

## Introduction

Technologies are playing an important role in development of crop and livestock farming and have the potential to be the key drivers of sustainable intensification of agricultural system. Sensors are now available in reduced dimension, reduced cost and increased performance which can be implemented and integrated in production system, allowing an increase of data and eventually an increase of information. Digital technologies are helping the farmers to take more wise decisions by providing better overview of their farms. In agriculture, smart sensors give data that helps farmers monitor and enhance their crops while also keeping up with changing environmental and ecosystem elements.

To meet the requirements of information, transmission, processing, storage, display, recording and control, a sensor can sense the measured data and convert it into an electrical signal or other required forms of information output according to a set of rules. Sensors are increasingly being applied to more and more areas such as agriculture and industry as the Internet of Things technology advances. Agriculture is being influenced by rapid societal growth, climate change, diminishing rainfall, and the desire for excess food to feed billions of people throughout the world. This has a negative effect on traditional farming methods. As a result, agriculture now has sophisticated sensors. The current situation calls for agriculture to become “smarter” by incorporating new and sophisticated technologies. There is need to create solutions for the most efficient use of resources while fulfilling the ever-increasing consumption demands of the global population. Sensors including air temperature and humidity, soil moisture, soil pH, light intensity, and carbon dioxide are frequently employed in modern agriculture to collect data on all aspects of crop growth, including nursery, growth, and harvest.

Smart agriculture, also known as precision agriculture, allows farmers to increase yields while utilising the least amount of water, fertiliser, and seeds possible. Farmers can begin to understand their crops on a micro scale, conserve resources, and reduce environmental consequences by deploying sensors and mapping fields. Smart agriculture has its origins in the 1980s, when civilian usage of the Global Positioning System (GPS) became possible. Farmers could monitor and apply fertiliser and weed treatments only to areas that needed it once they were able to precisely map their crop fields. Crop yield monitoring was first used in precision agriculture in the 1990s to give fertiliser and pH correction suggestions. As more factors are measured and entered into a crop model, more precise fertiliser, watering, and even peak yield harvesting suggestions may be given. Many smartphone apps have begun to incorporate Internet of Things (IoT) concepts, data gathering, and fast processing to provide small farmers with up-to-date, actionable information about seeding, weeding, fertilising, and watering. These apps collect data from handheld sensors, distant sensors, and weather stations to produce detailed analysis and useful recommendations.

A number of applications have been created specifically targeting small-scale farmers. Sensors can decide when more down force is needed, define when a crop is thirsty, detect illness before lesions show on the leaves, and guide how pesticides are sprayed both above and below ground. A mass flow sensor combined with GPS would forever alter farmers' perceptions of their land. The combination enabled them to link harvested grain to a specific field region and generate yield maps. A diverse range of solutions enables growers to be self-sufficient in their fields, resulting in more knowledge and better crops. The capacity to precisely monitor in-field variability and make data-driven decisions is changing how farmers run their businesses. The confidence generated by sensor data to make decisions for an entire field is a significant value point. The more familiar the producer becomes with soil moisture sensing, the more self-sufficient he will be while dealing with an uncommon scenario in the field. Traditional sensors were extremely expensive for farmers to purchase in large quantities, and as a result, the special resolution was insufficient to reflect this variability. Farmers will be able to collect data on their crops using the new, low-cost sensors without having to worry about unpredictability.

## Agricultural Sensors

A device that detects the changes in electrical or physical or other quantities and thereby produces an output as an acknowledgement of change in the quantity is called as a Sensor. Generally, this sensor output will be in the form of electrical or optical signal. There are different types of sensors used in agriculture (Fig. 1)

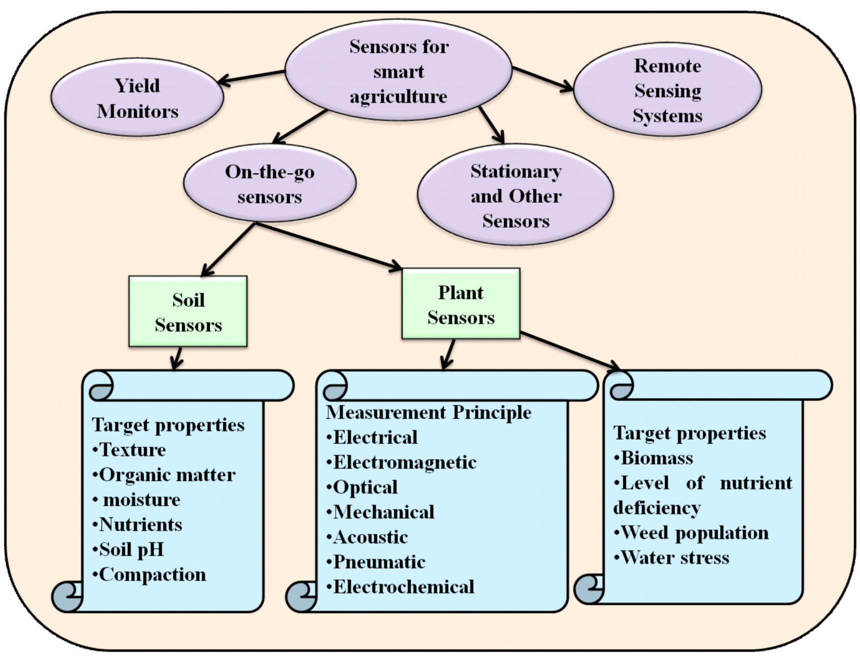


**Fig. 1.** Different types of sensors in agriculture (*Source:* H W Olfs, 2011)

***Soil temperature:*** World metrological organization (WMO) defines temperature as a physical quantity characterizing the mean random motion of molecules in a physical body (Iaea, 2008). Temperature can also be defined as a measure of how warm or cold an object is. It is related to the random thermal motion of the molecules in a substance. It is a measure of average translational kinetic energy of molecules in a material. The biggest changing range of soil temperature is 0 ~ 40 °C (Liu *et al.*, 2011). The optimum average range of soil temperature for plant growth is between 20 and 30°C. Temperature affects several processes in soil and soil ecosystem. As a result of this soil temperature measurement is required. Soil temperature affects: photosynthesis, respiration, transpiration, water potential of the soil, soil translocation and microbial activity. These can be classified as surface soil temperature factors and subsurface soil temperature factors. Surface soil temperature factors include factors like radiation from the sun, slope of the land, water content, vegetative cover and albedo (light reflected by the earth). Subsurface soil temperature factors include factors like heat flux from the surface, water content, bulk density and heat capacity of the soil. Some of the challenges of soil temperature measurement are: non-uniform temperature distribution, low resolution, low accuracy in modeling, self-heating effect and short life span of the sensors.

***Soil moisture sensor:*** The moisture of the soil plays an essential role in the irrigation field as well as in gardens for plants. Nutrients in the soil provide the food to the plants for their growth. Supplying water to the plants is also essential to change the temperature of the plants. The temperature of the plant can be changed with water using the method like transpiration. And plant root systems are also developed better when rising within moist soil. Soil moisture determines the water supply status of crops. Too high or too low soil moisture will affect the normal growth of crops above the ground. Only with suitable soil moisture, root water absorption and leaf transpiration can reach a balanced state, thereby promoting crop root growth. Soil moisture sensor measures the volume percentage of soil moisture by measuring the dielectric constant of the soil. The soil moisture tester method that meets the current international standards can directly and stably reflect the true moisture content of various soils.

***Temperature and humidity sensor:*** The air temperature and humidity sensor can monitor the air temperature and humidity changes in the agricultural planting environment. The default temperature and humidity monitoring ranges are -40°C~+80°C and 0% RH~100% RH, respectively. The wall-mounted enclosure can be wall-mounted in greenhouses, etc. A shading place with good air circulation in the environment; during outdoor monitoring, it can be installed in a solar radiation shield for outdoor weather monitoring together with the agrometeorological station.

***pH sensor:*** Agricultural soil conductivity and agricultural PH sensors are mainly used in agricultural monitoring with the water and fertilizer integrated machine system. They are mainly used to monitor the conductivity, pH, and temperature values of the fertilizer liquid after mixing and mixing, and display and upload to the water and fertilizer control system through the LCD screen.

***Illumination sensor:*** The Illumination sensor includes three parts: transmitter, receiver, and a detection circuit. All of them are composed of electronic part). It does not include mechanical working time. It can quickly monitor the light intensity of 0 to 200,000. Lux with a very short response time. The application of light sensor in greenhouse agricultural planting can help growers to accurately grasp the sunshine time law, light saturation point, and light compensation point of plant growth, and then adjust their light preferences through manual control technology to control and improve the scientific growth of crops in order to achieve high yields.

***Optical sensor:*** Optical sensors use light to measure soil properties. The sensors measure different frequencies of light reflectance in near-infrared, mid-infrared, and polarized light spectrums. Sensors can be placed on vehicles or aerial platforms such as drones or even satellites. Soil reflectance and plant color data are just two variables from optical sensors that can be aggregated and processed. Optical sensors have been developed to determine clay, organic matter, and moisture content of the soil.

***Mechanical sensors:*** Mechanical sensors measure soil compaction or "mechanical resistance" The sensors use a probe that penetrates the soil and records resistive forces through use of load cells or strain gauges. A similar form of this technology is used on large tractors to predict pulling requirements for ground engaging equipment. Tensiometers, like Honeywell FSG15N1A, detect the force used by the roots in water absorption and are very useful for irrigation interventions.

***Air flow sensors:*** Airflow sensors are used to record the number of gaseous substances present in the soil at a particular landscape after irrigation or to get an overview of the land that is to be cultivated before the seeding process. It determines the optimum pressure required to pump air to aerate the soil and make it more fertile. It is also used to determine the properties of the soil, its compaction, moisture-holding capacity, and more.

***Electrochemical sensors for detecting soil nutrient:*** It helps to collect soil chemical data. Electrochemical sensors provide information sensors for soil nutrient detection. Soil samples are sent to a soil-testing lab. Speciûc measurements, especially the determination of pH, are performed utilizing an ion-selective electrode. These electrodes sense the activity of particular ions, such nitrate, potassium, or hydrogen.

***Location sensors:*** These sensors determine the range, distance and height of any position within the required area. They take the help of GPS satellites for this purpose. Location sensors use GPS satellites to determine the longitude, latitude and altitude, i.e., the topographic attributes, which are useful in the precise positioning of precision agriculture. Typically, at least three satellites are required to triangulate a position. This sensor is used in vineyards to optimize the patterns of crop growth and yield. They are also useful when interpreting yield maps and weed maps. Furthermore, these assist in farm planning by analyzing field boundaries, existing roads and wetlands

***Electronic sensors:*** It installed on tractors and other ûeld equipment to check equipment operations. Then, cellular and satellite communication systems used to convey the data immediately to computers or e-mail it to people. The ûeld executive can then recover the information on their own computer or cell phone.

***Optoelectronic sensors:*** Optoelectronics deals with the interaction of electronic processes with light and optical processes. Devices where such interaction takes place, are called optoelectronic devices. Optoelectronic sensors, in general, use the characteristics of different materials to have a defined spectral signature. The system is composed of a light source (emitter) that emits light in a wavelength range and a sensor (detector) for specific wavelength ranges. Soil organic matter (SOM) sensor is one widely used under this category. Although inexpensive, the single-wavelength sensor needs to be recalibrated for the soil and moisture conditions that prevail at the time of use. The multiple wavelength sensors can utilize a single calibration to predict SOM over a range of soil moistures and soil types within a geographical area of several hundreds of kilometres. Besides, it can be used to sense soil moisture and cation exchange capacity (CEC).

***Electromagnetic sensors:*** Electromagnetic sensors use electric circuits to measure the capability for soil particles to conduct or accumulate electrical charge. Soil becomes a part of the electromagnetic circuit, and the change in the electrical conductivity is immediately recorded in a logger.

***Electrical conductivity sensors:*** There are two types of EC sensors: contact or non-contact. Contact EC sensors uses electrodes, usually in the shape of colters that make contact with the soil to measure the electrical conductivity. This approach has 2-3 pairs of colters mounted on a toolbar, and one pair applies electrical current into the soil, while the other two pairs of colters measure the voltage drop.

The data is recorded in a data logger along with location information. Contact EC sensors are very popular in precision agriculture because it is easier to cover large areas and is less susceptible to outside interference. Non-contact EC sensors work on the principle of Electromagnetic Induction (EMI) without contacting the soil surface directly. The instrument has a transmitter and a receiver coil, installed at opposite ends of a non-conductive bar located at opposite ends of the instrument. This is a digital and multi-frequency sensor that can operate in a frequency range of 300 Hz to 24 kHz.

***Ion selective electrode sensors:*** Ion Selective Electrode sensors measure the potential of a specific ion in a solution. They are also used to determine the nitrogen content in the soil. The potential is measured against a stable reference electrode of constant potential. The potential difference between the two electrodes depends on the activity of the specific ion in a solution. This activity is due to the concentration of the specification, allowing the end-user to make an analytical measurement.

***Plant Canopy Analyzer:*** Plant Canopy Analyzer uses a non-destructive method to easily and accurately measure Leaf Area Index (LAI). Plant Canopy Analyzer uses the gap fraction technique — the most powerful and practical tool available for indirect sensing of canopy structure. The gap fraction of a canopy is the fraction of view in some direction from beneath a canopy that is not blocked by foliage. The LAI measurements depend upon some assumptions. The foliage absorbs all light that is incident upon it. Foliage has low transmittance and reflectance in the waveband detected by the optical sensor (below 490 nm). With scattering correction, it is now possible to correct for errors caused by any transmittance or reflectance that does affect readings. The foliage elements are small compared to the area of view of each ring. This is ensured when the distance from the optical sensor to the nearest foliage element, such as a leaf, is at least four times the element width. The foliage is randomly distributed within certain foliage containing envelopes. These envelopes might be parallel tubes (a row crop), a single ellipsoid (an isolated bush), an infinite box (grass), or a finite box with holes (deciduous forest with gaps). Foliage is azimuthally randomly oriented. It does not matter how the foliage is inclined, but the leaves should be facing all compass directions.

Leaf Area Index (LAI) is the ratio of foliage area to ground area. The Plant Canopy Analyzer computes LAI from measurements made above and below the canopy, which are used to determine canopy light interception at five angles. These data are fit to a well-established model of radiative transfer inside vegetative canopies to compute LAI, mean tilt angle, and canopy gap fraction. The optical sensor of the plant canopy analyzer consists of a fisheye lens and an optical system. The fisheye lens takes in a hemispherical image, which the optical system focuses onto the five-ring photodiode optical sensor. Each detector ring views a different portion of the canopy or sky centered on one of the five view angles.

***Line quantum sensor:*** Photosynthesis is the bioenergetic process that allows plants to synthesize their organic compounds from incident solar energy interception. The part of this incident solar energy that drives photosynthesis in plants is defined as photosynthetically active radiation (PAR). It concerns the visible light waves range from 400 nm to 700 nm. The amount of PAR is usually expressed as Photosynthetic Photon Flux Density (PPFD, $\mu mol\ m^{-2} s^{-1}$). Although this parameter is crucial as input data for many ecophysiological models it is often not measured in weather stations. Indeed, for green foliage under non-stressed conditions, it is approximated as a constant value (conversion energy) of the measured global solar radiation. Quantum sensors measure photosynthetically active radiation (PAR). Single quantum sensors are used to take PAR measurements at the level of a plant canopy, while 'Line quantum sensors' contain multiple sensors for measuring a spatial average of PAR. All sensors are fully potted and weatherproof, and can be used to take underwater measurements. Spectrum quantum sensors (Apogee 500 series) feature an improved spectral response from 412 to 682 nm and produce accurate PAR measurements under nearly any lighting conditions. While other quantum sensors sensitive to light from 469 to 653 nm and produce accurate PAR readings in most lighting conditions but are not recommended for use under red and blue LED lights. Typical applications include PPFD (Photosynthetic Photon Flux Density) measurement over plant canopies in outdoor environments, greenhouses, and growth chambers, and reflected or under-canopy (transmitted) PPFD measurements in the same environments. Quantum sensors are also used to measure PAR/PPFD in aquatic environments, including salt water aquariums where corals are grown.

***Microorganisms and pest sensors:*** Many fungal infections can be associated with temperature and humidity conditions. Early detection allows the farmer to protect the crop from widespread infections. Microbial, viral, or pest infection causes a huge loss in agricultural production. For remote automatic pest monitorization, a pest insect trap is attached with low-power image sensor technology. These traps form a Wireless Sensor Network (WSN) and the images are sent through wireless one-hop broadcast communication to a host control station. Microbial root colonization in potatoes can be detected by a confocal laser scanning microscope by analyzing the metabolites produced by the microbes, which fluoresces. *Zymoseptoria tritici* in wheat can be detected by Infrared Thermography technology.

***Drones in agriculture:*** Drones are increasingly being used in the agricultural sector to help reduce error by providing more accurate data and facilitating a quicker response to adverse weather conditions and disasters, such as floods or droughts. Drones can be used in various aspects of agricultural work, including seeding, livestock, spraying, maintaining insecticide and pesticide levels, and monitoring irrigation systems. Agricultural drone technology has undergone many improvements in the last few years. The advantages of drones in farming are becoming more obvious to farmers. Drone applications in agriculture include mapping and surveying to crop-dusting and spraying. On the surface, agricultural drones are no different than other types of drones. The application of the UAV simply changes to fit the needs of the farmer. There are, however, several drones specifically made for agricultural use. As the drone flies, it automatically takes pictures using onboard sensors and the built-in camera, and uses GPS to determine when to take each shot. But if your drone does not have these automatic features, then one person needs to fly the drone while the other takes the photos. Drones are capable of spraying crops with far more precision than a traditional tractor. This helps reduce costs and potential pesticide exposure to workers who would have needed to spray those crops manually.

***Remote sensing sensors/instruments:*** Each active sensor in remote sensing directs its signal to the object and then checks the response – the received quantity. The majority of devices employ microwaves since they are relatively immune to weather conditions. Active remote sensing techniques differ by what they transmit (light or waves) and what they determine (e.g., distance, height, atmospheric conditions, etc.).

- **Radar** is a sensor assisting in ranging with radio signals. Its specific feature is the antenna emitting impulses. When the energy flow in radar active remote sensing meets an obstacle, it scatters back to the sensor to some degree. Based on its amount and traveling time, it is possible to estimate how far the target is.
- **Lidar** determines distance with light. Lidar active remote sensing implies transmitting light impulses and checking the quantity retrieved. The target location and distance are understood by multiplying the time by the speed of light.

- **Laser altimeter** measures elevation with lidar.
- **Ranging** instruments estimate the range either with one or two identical devices on different platforms sending signals to each other.
- **Sounder** studies weather conditions vertically by emitting impulses, in case it falls to the active category.
- **Scatterometer** is a specific device to measure bounced (backscattered) radiation.

Apart from a variety of implementations, active remote sensors basically have no restrictions as to research conditions. Active types of remote sensing systems fully function at any time of the day as they do not require sunlight, and they are relatively independent of atmospheric scatterings. Various types of remote sensing technology find implementations both in scientific branches and far more practical industries. Shuttle Radar Topography Mission collected the Earth's elevation data. Lidar active remote sensing in the sky assisted in the elaboration of digital models of our planet's surfaces. Data acquired with remote sensing instruments serve agriculturalists and foresters. They are critical in hard-to-reach places in marine sciences and rescue missions. Sounders assist in developing weather forecasts with vertical profiles of humidity, precipitations, temperature, and absence/presence of clouds. Passive sensors in remote sensing do not streamline energy of their own to the researched object or surface, unlike active ones. Passive remote sensing depends on natural energy (sunrays) bounced by the target. For this reason, it can be applied only with proper sunlight, otherwise there will be nothing to reflect. Passive remote sensing employs multispectral or hyperspectral sensors that measure the acquired quantity with multiple band combinations. These combinations differ by the number of channels (two wavelengths and more). The scope of bands includes spectra within and beyond human vision (visible, IR, NIR, TIR, microwave). The most popular passive remote sensing examples of devices are various types of radiometers or spectrometers.

Passive remote sensing sensors/instruments are, Spectrometer distinguishes and analyzes spectral bands. Radiometer determines the power of radiation emitted by the object in particular band ranges (visible, IR, microwave). Spectroradiometer finds out the power of radiation in several band ranges. Hyperspectral radiometer operates with the most accurate type of passive sensor that is used in remote sensing. Due to extremely high resolution, it differentiates hundreds of ultimately narrow spectral bands within visible, NIR and MIR regions. Imaging radiometer scans the object or a surface to reproduce the image. Sounder senses the atmospheric conditions vertically. Accelerometer detects changes in speed per unit of time (e.g., linear or rotational).Among different examples of passive sensors in remote sensing, Landsat definitely stands out as the most long-lasting Earth-observing mission. It monitored our planet and recorded the obtained data enabling us to analyze the way it changed within a 40-year span. The mission's great plus is that the information is accessible to the public, with interpretations applied in geology, mapping, ecology, forestry and agriculture, marine sciences, meteorology, etc.

***Nanosensors in agriculture:*** The role of nanomaterials-based biosensors in agriculture is now key research area of interest among scientists and researchers (Fig. 2). A naosensor is a device consisting of a biomolecule, a matrix, transducer and signal processing unit. An analyte of interest is detected in any agricultural sample based on specific biomolecule interaction reaction. Now the research focus is directed in search of novel nanomaterials, nanocomposites and nanostructures for improving the biosensing characteristics. Nanomaterials of different shapes and size presently being used in different application areas are carbon nanotubes, nanorods, nanowires, quantum nanodots, graphenes etc.

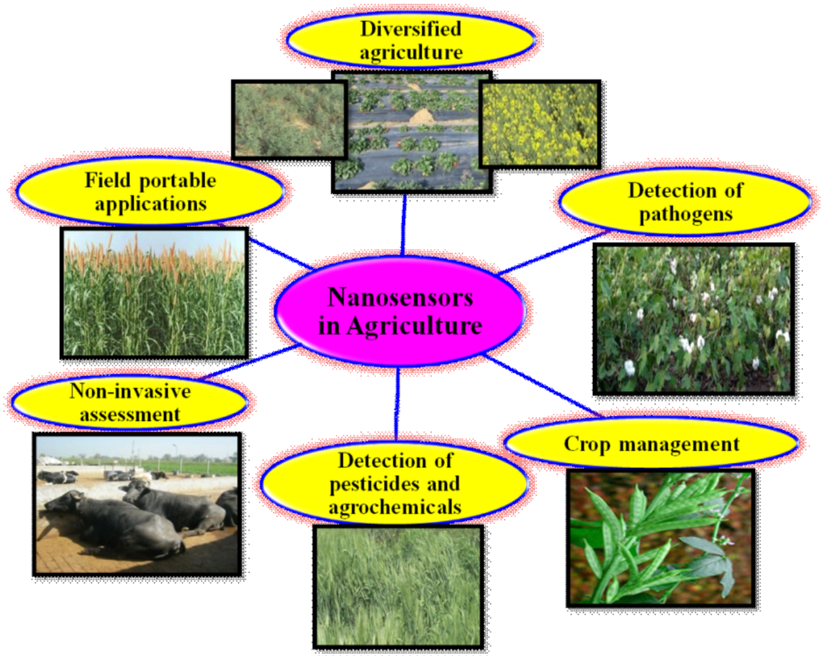


**Fig. 2.** Application areas of nanosensors in agriculture

***Nanosensor for soil:*** The soil is very important for production of food its preservation depends on the monitoring of pollution in it to avoid drastic impacts on agriculture. Among various pollutants, pesticides, heavy metals and herbicides etc. are reportedly found in agricultural soil. Due to fast moving civilization, there is continuous addition of toxic elements in natural resources such as land, water and air. The nickel contamination leads to hindering the cell division and plant growth. Another element, chromium affects seed germination, yield, roots and shoot growth. Biosensors are very useful for evaluation of soil health with more precision and accuracy as compared to conventional techniques. The biosensors based on colorimetric and potentiometric techniques can determine these metals even at very low concentrations.

***Nanosensor for food:*** There are numerous applications of naosensors in food industry (Fig. 3). Presently there is huge demand for the on the spot testing equipment for food quality and safety. Market is flooded with lots of packaged and processed food items. There is need to determine whether the proper storage conditions have been maintained or not. Besides, the non-compliance to the food standards in terms of preservent, ingredients and storage conditions needs to be checked. Nanosensors can be used to detect presence of any foreign particle, contaminant, toxicant, pathogen etc. in food rapidly.

This technique can be integrated with decision support systems for early warning of outbreak of any disease. The biosensors are very target specific as they use enzyme or antibody as the molecular recognizing material. There are various arenas in food industry where nanosensor can find potential applications such as:

***Vitamins analysis:*** Various biosensors can be developed for monitoring interactions among protein with the vitamins on a sensor chip. The resulting response in the form of an electrical signal or colorimetric response can be further processed for analysis.

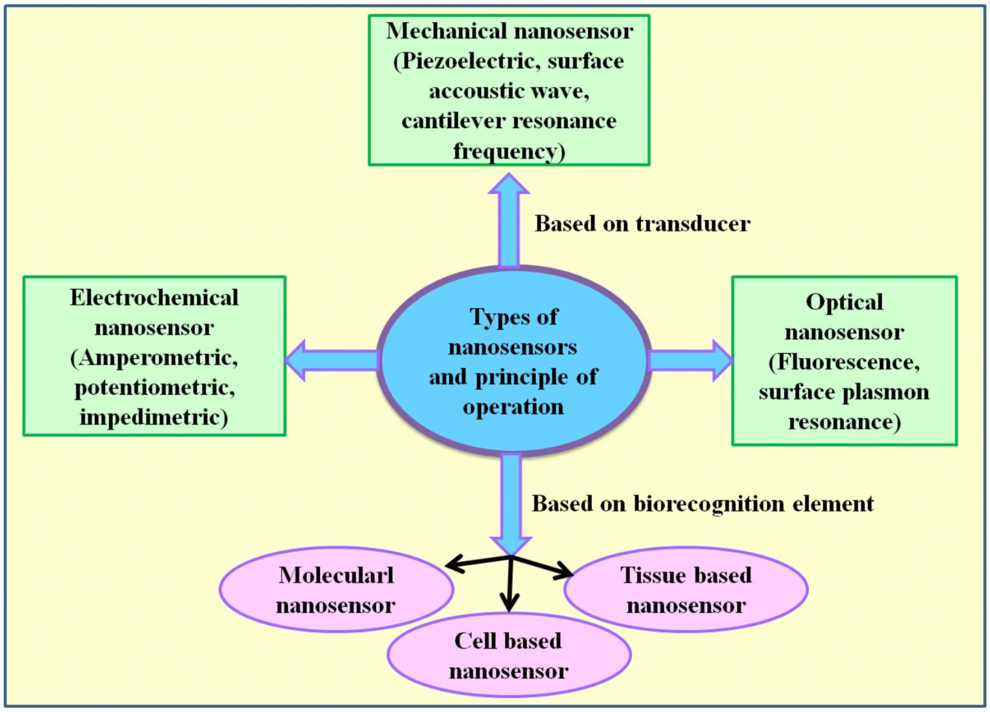


**Fig. 3.** Various types of nanosensors in agriculture

***Antibiotics detection*:** Many of the medicines inform of antibiotic leave their residual effect in animals. The presence of such antibiotics can be detected in animal products such as milk, eggs, meat etc. Nanosensors sensitively and accurately analyze the presence of such antibiotics in a short time.

***Detection of microbial contamination:*** Now-a-days, immune-nanosensors can be used to detect microbial contamination in food while undergoing various processes such as harvesting, storage, transportation etc. in whole food supply chain. Such nanosensors are based on the surface immobilization of specific antibodies onto selective electrodes based on microorganism to be detected.

***Nanosensors for livestock management and production:*** Based on the specificity and sensitivity of biosensors, these are now laying pathways for the development of handy gadgets and instruments for the animal diagnostic and health management. Precision livestock farming applies a wide variety of technologies including biosensors as the core technology. There is need of nanosensors for the pathogens detection, ovulation prediction, progesterone monitoring etc. For animal wellbeing, biosensors are desirable for the measurement of biological effects such as genotoxicity, immunotoxicity, biotoxins and endocrine effects.

***Nanosensors for plants:*** There are numerous infield processes that are essential to be monitored for the plant growth and development. To keep a vigilant watch over the dynamics of such events, there is need of smart and sensitive technology which can act as real time monitoring system. The rate of photosynthesis, concentrations of micro and macronutrients, phytohormones levels etc. affect the overall productivity. Biosensors have played an essential role in detection of plant stress indicators, chlorophyll levels, water content etc.

***Disease detection:*** Food loss is one of the persistent issues in agriculture and its major cause behind this is pathogens (bacteria, viruses and fungi). There is urgent need to reduce these losses occurring at different levels in crops (during growth, harvest and postharvest processing). These pathogens can be detectable by DNA-based biosensors or specific immunosensors due to their specificity for the target.

***Detection of toxic compounds:*** Bacteria, viruses, fungi, and toxins are capable of causing serious damage to both animals and humans in form of mycotoxins, exotoxins. Food and water may get contaminated with these toxins. In present times, the nanosensor platforms are needed for detection of such harmful toxins, in sensitive and specific manner, directly from complex sample matrices.

***Stress detection:*** Various plant stresses such as chemical stress, toxic stress, oxidative stress etc. affect the plant growth and development and hamper the normal physiochemical processes. These stresses conditions are generally accompanied with release of some indicators in plants. Nanosensors are found to be very useful in identification of these stress conditions using various transducer techniques such as amperometric, electrochemical and optical.

### *Benefits of using sensors in agriculture*

Using agricultural sensors in precision farming helps farmers make a switch from the traditional models of farming and move towards a data-driven approach. This approach helps them optimize their return on investment by optimizing their yield according to the market requirements and cut any expenses that could affect. Sensors also help farmers take an analytical approach in every step involved in the life cycle of a crop, beginning from seed selection to harvesting. To get the maximum benefit of the data collected by agricultural sensors, farmers must have a farm system of integrated sensors in place to monitor all the data in one place. In the modern farming the sensor data that is received on field and IoT systems can be hooked up and integrated to the dashboard to give you a real time analysis of your farm. Sensors can help in collecting, monitoring, improvising on the farming data as well as integrating with other software platforms. It also acts as a platform where you can also seamlessly connect with your business partners such as field-staff or vendor, be it agri-consultant, dealer, manufacturer or retailer. Everyone who has a role to play in the Agribusiness sales cycle will also benefit greatly from having a single management system in place which ensures transparency. Labour shortages and the need for food to feed an increasing global population, agricultural robots and technologies now commonly used by farmers. The vision and mission of machine education now allow robots and sensors to see and train surroundings, and of the cheaper costs of smart sensors, they used for more than a year. New innovative sensing technology allows farmers to monitor their fields' pest groups remotely and take immediate action to protect their crops, using online cloud services and a dashboard.

With the exponential growth of world population, according to the UN Food and Agriculture Organization, the world will need to produce 70% more food in 2050, shrinking agricultural lands, and depletion of finite natural resources, the need to enhance farm yield has become critical. Limited availability of natural resources such as fresh water and arable land along with slowing yield trends in several staple crops, have further aggravated the problem. Another impeding concern over the farming industry is the shifting structure of agricultural workforce. Moreover, agricultural labor in most of the countries has declined. As a result of the declining agricultural workforce, adoption of sensors based farming practices has been triggered, to reduce the need for manual labor. Sensors based agricultural practices are focused on helping farmers close the supply demand gap, by ensuring high yields, profitability, and protection of the environment. The approach of using sensor technology to ensure optimum application of resources to achieve high crop yields and reduce operational costs is called precision agriculture. Sensing systems in agriculture comprise specialized equipment, wireless connectivity, software and IT services. The farmers can monitor the field conditions from anywhere. They can also select between manual and automated options for taking necessary actions based on this data. For example, if the soil moisture level decreases, the farmer can deploy sensors to start the irrigation. Smart farming is highly efficient when compared with the conventional approach.

## Future Prospects

Smart farming based on sensing devices is paving the way for what can be called a third green revolution. Following the plant breeding and genetics revolutions, the third green revolution is taking over agriculture. That revolution draws upon the combined application of data-driven analytics technologies, such as precision farming equipment, IoT, big data analytics, Unmanned Aerial Vehicles (UAVs or drones), robotics, etc. In the future, this smart farming revolution depicts, pesticide and fertilizer use will drop while overall efficiency will rise. Sensors will enable better food traceability, which in turn will lead to increased food safety. It will also be beneficial for the environment, though, for example, more efficient use of water, or optimization of treatments and inputs. Therefore, smart farming has a real potential to deliver a more productive and sustainable form of agricultural production, based on a more precise and resource-efficient approach. New farms will finally realize the eternal dream of mankind. It will feed our population, which may explode to 9.6 billion by 2050.

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# Risk Management in Agriculture

**Sanjay Srivastava**[1]
*Chief, Disaster Risk Reduction,*
*UN Economic and Social Commission for Asia and the Pacific, Bangkok 10200, Thailand*
*Email: srivastavas@un.org*

## Introduction

Over the past two decades, Asia and the Pacific has made significant progress in managing disaster risk. But the arrival of COVID-19 presented an additional biological shock – not just to health and survival but to national economies and whole societies. The pandemic, combined with the persistent reality of climate change, is reshaping the Asia-Pacific disaster risks cape and demanding a much more systemic approach to manage risk particularly in agriculture sector – where risk is disproportionately accumulated. In the past two years, Asia and the Pacific has been reeling after multiple blows from successive disasters amidst multiple waves of the COVID-19 pandemic. South Asia was the worst hit in 2021, with millions of people affected by multiple disasters and little time to recover from one to the next. India, Bangladesh, and Nepal were severely impacted by floods and cyclones in 2021. China's Henan Province was affected by severe flooding in July. In Southeast Asia, Indonesia was worst affected by disasters. Afghanistan faced drought combined with associated economic collapse unfolding slow but devastating consequences. 2021 also saw large scale flooding along with a number of typhoons in Thailand, Myanmar and the Philippines. Further, Pacific Island countries faced significant flooding due to storms and rising sea tides.

In the year 2021 India witnessed multiple intense cascading risk scenarios. Amid the Delta variant of COVID-19 that triggered the second wave, India was faced with five cyclonic storms — Cyclone Tauktae, Yaas, Gulaab, Shaheen and Jawad in the Bay of Bengal and the Arabian sea. The erratic monsoons left a trail of devastating floods across Tamil Nadu, Maharashtra, Kerala, Bihar, Uttarakhand, Uttar Pradesh, and Assam. Agriculture is the sector most impacted by these disasters. Therefore, disasters slow down economic growth, especially in countries where agriculture sector is a major component of the economy. For example, agriculture contributes as much as 30% to national GDP in Cambodia. The sector employs over 30% of the labour force in developing countries such as Cambodia, India, Indonesia, Philippines, Sri Lanka, and Viet Nam. Disasters also have a direct impact on the livelihoods of millions of small farmers and rural communities in developing countries. Disasters can change agricultural trade flows and cause losses in agricultural-dependent manufacturing subsectors such as the textile and food processing industries.

## Asia-Pacific Disaster Risk Scape

Understanding the risk is at the heart of resilience building and disaster prevention. ESCAP's flagship publication, (Asia-Pacific Disaster Report, 2019) captures a comprehensive picture of both slow-onset and extreme event disaster risk in the Asia-Pacific region for the first time. Annualized

[1]Sanjay Srivastava did his Ph D (1989) in Agricultural Physics from Indian Agricultural Research Institute, New Delhi

economic losses more than quadruple to USD$675 billion when slow onset disasters are added to the region's risk scape (Fig. 1). As climate change interacts with environmental degradation, slow onset disaster such as agricultural droughts intensify and expand volumetric in terms of their impacts on larger population, geographical areas and economic/social implications. The Report presents a 'climate sensitive' regional 'risk scape', which captures the absolute average annual loss (AAL) in US dollars, for each hazard type within each country.

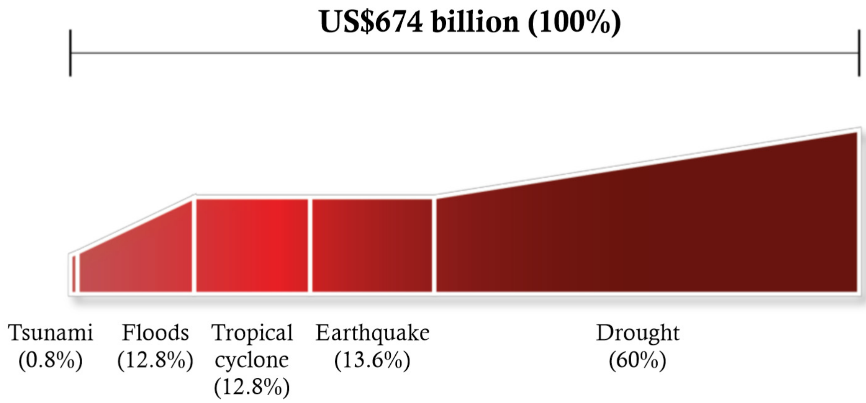



**Fig. 1.** Asia-Pacific regional risk scape (average annual losses) [Source: ESCAP, based on probabilistic risk assessment]

Floods in the Asia-Pacific region have been most frequent and devastating both in terms of fatalities and economic losses. Globally, 10 out of the top 15 countries with the most people and economies exposed to annual river floods are in the Asia-Pacific region. In order of population exposed to flood risk, they include India, Bangladesh, China, Viet Nam, Pakistan, Indonesia, Myanmar, Afghanistan, Thailand, and Cambodia. The *Asia-Pacific Disaster Report 2019* forecasts a substantial increase in flood-related losses, with the problems expected to worsen by 2030 (Fig. 2). China, India, Bangladesh, and Pakistan will experience losses two to three times greater than in the reference year of 2010. Under the severe climate change scenario, India will be the worst affected,

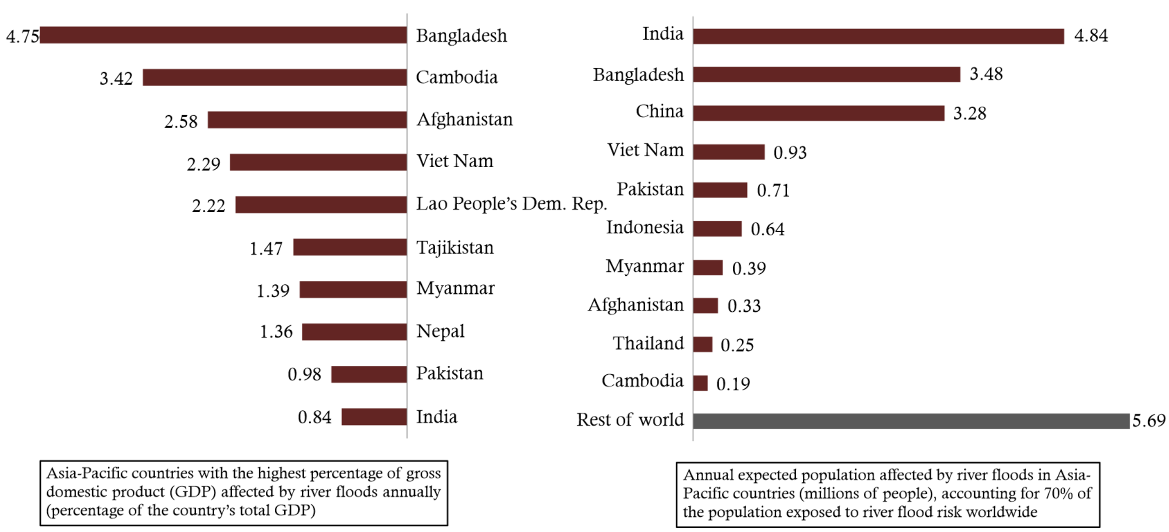



**Fig. 2.** Per cent of GDP (left) and expected number of people (millions, right) affected by floods annually [Source: ESCAP based on World Resource Institute Flood database]

with annual losses of nearly $50 billion, followed by China, Bangladesh, and Pakistan. While flooding can be analyzed by country, much of the excess water spreads across the region's major river basins and crosses national frontiers. Under the moderate and severe climate change scenarios, the transboundary flood losses will be 2 to 6 times greater in the Ganga-Brahmaputra and Meghna basin; 1.5 to 5 times in the Indus basin: 1.2 to 2 times in the Mekong basin; and 1.1 to 1.5 times in the Amur basin (Asia-Pacific Disaster Report, 2017 ).

## Impact of Disasters on Agriculture Sector

The recent FAO 2021 assessment report (FAO, 2021), based on the data from 71 Post-Disaster Needs Assessments (PDNA) conducted between 2008–2018, highlights that agriculture continues to be a crucial sector when it comes to disaster impact. Over that period, agriculture – including crops, livestock, forestry, fisheries and aquaculture – absorbed 26 percent of the overall impact caused by medium- to large-scale disasters in low- and lower-middle-income countries. When compared to the other productive sectors like industry and commerce, agriculture bears the disproportionate share of 63% of the damage and loss from disasters.

For climate-related disasters such as floods, droughts, and tropical storms, more than 25% of all damage and losses occur in the agriculture sector. Agriculture is the single most affected sector by droughts, absorbing on average about 84% of all the economic impact. Based on the PDNA reviews, the crop subsector is the most affected by natural hazards with almost 60% of these damage and losses caused by floods, followed by 23% by storms. Livestock is the second most affected subsector after crops with drought having caused the biggest losses. Out of the 78 disasters reported in the PDNA, 45 caused damage and losses in the fisheries subsector, representing almost 6% of all damage and losses within the agriculture sector. Over 70% of this economic impact was caused by tsunamis which are an infrequent event, yet storms such as cyclones and typhoons cause roughly 16% of the economic impact on fisheries followed by floods with 10%. The impacts on agriculture subsectors are different because of the respective exposure and vulnerability associated with each hazard.

### *Macro-economic impact*

As mentioned before, in the agrarian countries, there is a close linkage of growth with agriculture, industry, and services sectors of the economy. Over the years, despite the substantial increase in the share of the services sector in the GDP, studies suggest that the agricultural sector still plays an important role in determining the overall growth rate of the economy given its demand linkages with the other sectors. In the Indian context, empirical results of an experiment reveal that 1 percentage fall in agriculture is likely to cause a setback to the industrial output by 0.52% points, causing a combined effect of a fall in the industrial sector that will cascade into a loss in service sector by about 0.24% point. The fall in all the three sectors resulted into a deceleration of 0.52% point in the overall growth of GDP (Sastry *et al*., 2003). The cascading impact of 2012-2013 drought in the state of Tamil Nadu, India, where agriculture contributes to 18% of state's GDP and more than 40% population is dependent on agriculture, provides substantive evidence in support of this experimental finding (Sugato Dutt, 2015). The effect of 2012-2013 drought, assessed by Tamil Nadu State Planning Commission, indicates that the fall of agricultural growth to the extent of 32 per cent results in reduction by 16.7% and 7.7% respectively in industry and service sectors. The cascading impacts of drought were clearly transmitted through supply channel and inter-sectoral linkages. Similarly, in 2010, floods in Pakistan led to drop in agricultural growth from 3.5 to 0.2%. Subsequently, the national GDP declined from 2.8 to 1.6%. In Pakistan, agriculture contributes

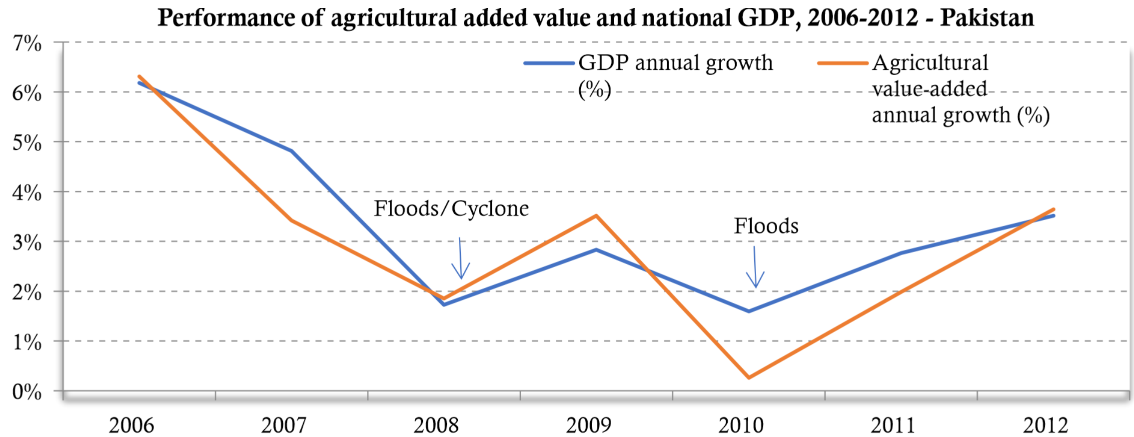



**Fig. 3.** Linkages between disaster impacts to agriculture vis-vis national GDP in Pakistan [*Source:* ESCAP based on the data from FAO, Impact of disasters on agriculture and food security, 2015]

about 24% of GDP. Fig. 3 shows the strong co-relation between agriculture and GDP (FAO, 2015). The higher loss to damage ratio indicates potential disruptions in economic flows due to disaster with impacts on the agriculture and other sectors.

### *Long-term impacts on food production systems*

Disasters affect all aspects of food security: economic and physical access to food, availability and stability of supplies, and nutrition. Disaster losses are accentuated in poor households and communities and result in long-term consequences for food security. Thus, they contribute to widespread hunger (Box I). More than 80% of the world's food insecure people live in countries prone to natural hazards. The analysis of Inform Risk index indicates that most of the high disaster risk countries are characterized by low TFP. The index includes the population affected by disasters – drought, floods, cyclone, earthquake and tsunami vis-a-vis agricultural total factor productivity (TFP) growth indices over 1961-2013 using for primarily FAO data, supplemented in some cases by national statistics.

At the micro-level, most of the potentially affected people in high risk and low TFP zones have an alarmingly low asset base, depend on agriculture for a living and face increasing exposure to disaster risk, which is exacerbated by price volatility, population growth, land and ecosystem degradation, climate change and other drivers (O'Connor *et al.*, 2017). A total of 90 million hectares of agricultural land was lost in the region between 2000 and 2013. Between 1993 and 2013, the region lost 5.3%, or 35 million hectares, of its arable land due to land degradation through soil and water erosion, alkalinity/salinity, waterlogging etc. and conversion to other uses, such as industrial parks and urban centres (ESCAP, 2015). Prolonged drought contributes substantially to land degradation. Indeed, land degradation affects 1.5 billion people globally whose livelihoods depend directly on exploiting degraded areas and is closely associated with poverty, as 42% of the very poor live in degraded areas compared with 15% of the non-poor. Major agriculture systems of Asia and the Pacific are at different stages of land degradation. A high degree of erosion in paddy grown areas of temperate, dry range land and desert terrains contribute to land degradation in key agricultural systems and reduce productivity substantially. Further, disasters in quick succession degrade the ecological foundations of agricultural produce, which takes a long time to recover. For example, between 2006 and 2013, the Philippines was hit by 2 severe droughts and 50 typhoons, which had a substantial impact on its agriculture sector (Box I).

**Box I. The cost of natural disasters on the agriculture sector in the Philippines**

Disasters in the Philippines have a high impact on its agriculture sector. Between 2006 and 2013 the government estimates that disasters damaged over 6 million hectares of crops. During this period, the total damage and losses in the agriculture sector were estimated by the government to be USD 3.8 billion, caused by 78 natural disasters (2 droughts, 24 floods, 50 typhoons/tropical storms, 1 earthquake and 1 volcanic eruption).

Most of the production damage and losses were caused by typhoons/storms, amounting to USD 3.5 billion or 93 percent. Much of the damage and losses in the agriculture sector were in the crop subsector with USD 3.1 billion. Central Luzon (region 3) has been the most affected by natural hazards during the 2006–2013 period, followed by Davao (region 11), Eastern Visayas (region 8) and Cagayan (region 2). In Bicol (region 5) alone, the total agriculture damage and losses were about USD 260 million, which is 6.8 percent of total damage and losses for the country as a whole. Also, typhoons and tropical storms resulted in damage and losses of USD 221 million or 85 percent of all agriculture damage and losses in Bicol region.

[*Source: The Impact of disasters on agriculture and food security, FAO 2015*]

## Developing a Resilient Agriculture Sector in a Riskier World

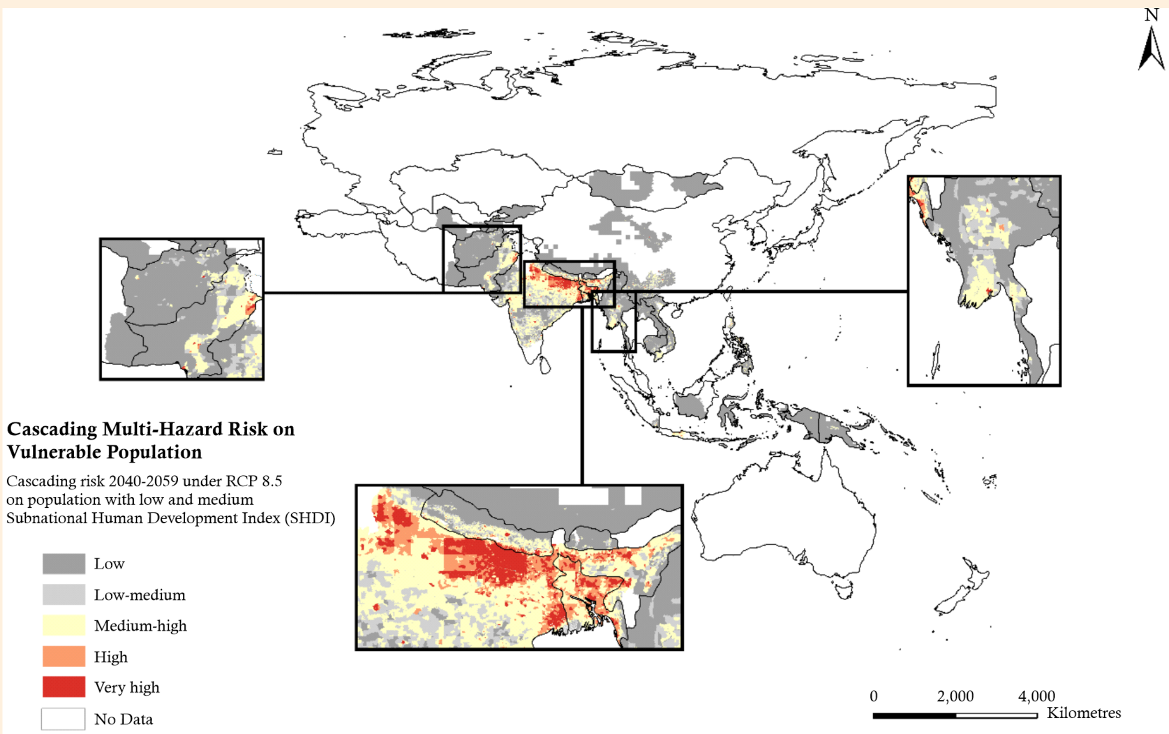
The Sixth Assessment report (AR 6) of the Intergovernmental Panel on Climate Change (IPCC) *Climate Change 2021: The Physical Science Basis* presents new scenarios with greater certainty in understanding the changes taking place in climate extremes and their attribution to human influence since the Fifth Assessment Report (AR5). Using the latest Sixth Coupled Model Intercomparison Projects (CMIP6), it offers the improved knowledge of climate processes, paleoclimate evidence and the response of the climate system to increasing radiative forcing and provide a best estimate of equilibrium climate sensitivity of 3°C. To bridge the science and policy gaps, the AR 6 uses the Shared Socio-economic Pathways (SSPs) to describe "five broad narratives of future socio-economic development" from potentially below 1.5C best-estimate warming to over 4C warming by 2100. One of the key highlights of the AR 6 is that the difference between 1.5- and 2-degrees global warming is quite substantial: every increment of a degree translates into increased risks. For example, every additional 0.5°C of global warming causes clearly discernible increases in heavy precipitation (high confidence), as well as agricultural and ecological droughts in some regions (high confidence); Similarly, every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves (very likely) (Seneviratne *et al*., 2021). The highlight of the Glasgow climate pact 2021 at the Conference of the Parties (COP 26) has been the commitments on reducing greenhouse gas emissions. The Pact also includes some key elements that will boost adaptation in a riskier world. As risk continues to outpace resilience, widening adaptation gaps are reaching tipping points in the vulnerable contexts of agriculture systems (Box II).

Agriculture is facing an unpresented climate risk scenario, interacting in a hyperconnected world and a precipitously changing landscape. Asia-Pacific Disaster Report, (2021) introduces five key prioritizes to adapt to climate change. Those adaptation priorities include strengthening early warning systems to minimize the loss of lives, making water and new infrastructure resilient to reduce the economic cost, improving drylands to combat drought and desertification, and protecting mangroves to reduce coastal hazards. Estimates indicate that 54 per cent of all future adaptation costs will need to be spent on the water sector, more than all other sectors combined (Thacker *et al.*, 2021). These costs originate from hazard protection provided by this sector that can reduce risks from floods, sea level rise, storm surge events, and other climate impacts. Whilst traditional built

**Box II. Climate change impacts on the most vulnerable small holders' farmers**

In the moderate and worst-case climate scenarios, climate change and related disasters will profoundly affect the region's poorest and most vulnerate people. The extent of the risk can be assessed using the UNDP multidimensional poverty index which measures multiple deprivations at the household and individual levels in health, education and standard of living. ESCAP has used subnational human development index data to locate the most vulnerable populations under the worst-case scenario of RCP 8.5. These are in the GBM basin, parts of South-East Asia, and some parts of South-West Asia. (See the Figure below). For instance, in Bangladesh, under RCP 8.5, almost 70 per cent of the multidimensional poor are exposed to cascading hazards – pushing the populations into intergenerational cycles of deprivation.

**Vulnerable populations with low or medium HDI under multi-hazard risks, at RCP 8.5**




Sources : ESCAP calculations, based on Global Assessment Report on Disaster Risk Reduction (GAR) Risk Atlas, 2015; Climate Change Knowledge Portal, 2018; Disability-Adjusted Life Years (DALYs) estimates 2000-2019; Sub-National Human Development Index (SHDI) Version 4.0 and UN WPP-Adjusted Population Density 2020, v4.11.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

protective infrastructure (e.g., sea walls) will play an important role in risk reduction, nature-based solutions (such as reforestation, mangroves and wetlands) represent an effective and resource-efficient alternative that can offer a multitude of co-benefits including carbon sequestration and the enhancement of habitats. Policies that protect those exposed to hazards, those most vulnerable within society, will also play a critical role in managing overall climate risk.

## Moving Forward

### *Suggested research agenda from the perspectives of agricultural physics*

Geo-spatial and earth observation systems in conjunction with drone, connected devices data, IoT and social media are making transformative impacts in managing the complexities of disaster

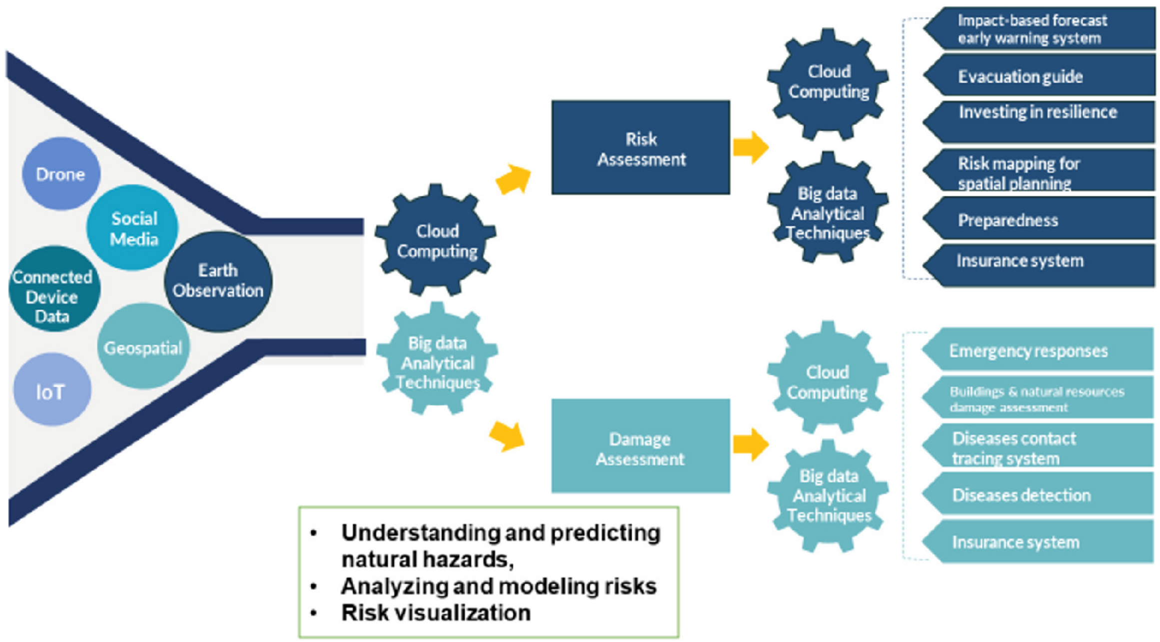



**Fig. 4.** Emerging applications of earth observations and geo-spatial technologies in disaster risk reduction. [Source: Asian Development Bank Report 2020: Leveraging Technology and Innovation for Disaster Risk Management and Financing]

and climate risks. Enabled through cloud computing and big data analytics techniques, earth observations and geo-spatial technologies offer precise and near real time solutions for (i) understanding and predicting natural hazards, (ii) analyzing and modeling risks, and (iii) risk visualization (Fig. 4). The focus research areas therefore include:

*Understanding and predicting natural hazards*: Geo-spatial analysis of floods, storm surges, landslides, soil erosion and other hazards; modelling to predict where and when hazards may occur in future; emphasis on drivers and triggers: earthquakes, land use change, climate variability and extreme climate events.

*Analyzing and modelling risk*: Using expert-based, data-driven and physically based modelling approaches; elements of risk analysis, vulnerability evaluation for multi-hazard risk assessment; urban and rural risk; integrating community-based and technical approaches.

*Risk visualization*: Geo-spatial risk visualization in space and time; satellite and airborne remote sensing tools for post-disaster damage assessment; spatial decision support systems; spatial data infrastructures for rehabilitation and reconstruction.

These focus areas can address some of the outstanding operational challenges that key stakeholders such as the governments, international and civil society organizations, private sectors, and others confront in managing disaster and climate risks.

### *From cutting edge research to operational solutions*

With cutting edge research, the focus is to work towards development of operational solutions in disaster risk management to support the policies and programmes of the State and Central governments and other related stakeholders including the UN, the World Bank, Civil Society Organizations etc.:

*Operationalizing Disaster Risk Management framework***:** This is essentially to accelerate the paradigm shift from re-active to pro-active approaches such as managing disasters to managing risk and building agriculture resilience in this cross-cutting field of development. India's National Policy on Disaster Management (2009) and the National Disaster Management Plan (2016) focus on disaster resilience and integrating the Sendai Framework for Disaster Risk Reduction as well as the SDGs. With the recommendations of the XV Finance Commission report, India has dedicated resources for the entire cycle of disaster mitigation, preparedness, relief and rescue, as well as recovery and reconstruction.

*Scaling up resilience through open data and geo-spatial applications:* It's important to develop the skills and tools for sharing geospatial data, community mapping and citizen science for disaster and climate risk management, and new approaches for communicating complex risk data to a range of stakeholders. Over the past years, India has produced a rich "base" of map information through systematic topographic surveys, geological surveys, soil surveys, cadastral surveys, various natural resources inventory programmes and the use of the remote sensing images. Further, with the availability of precision, high-resolution satellite images, data platforms such as National Spatial Data Infrastructure (NSDI) of Department of Science and Technology, and National Database for Emergency management (NDEM) of Ministry of Home Affairs (MHA) and National Remote Sensing Centre (NRSC), Indian Space Research Organization (ISRO), data from multiple platforms and sources are translated into actionable information to support decision making process for disaster risk management.

*Managing floods:* The geospatial tools and techniques help improve managing urban floods by i) assessing and communicating urban flood risk, ii) planning and prioritizing urban flood risk management investments, iii) designing and implementing these investments and iv) operating and maintaining these investments. Effective and long-lasting strategies for flood control and management involve structural and non-structural measures along with the use of modern technologies. The recent report of the committee constituted by Niti Aayog for Formulation of Strategy for Flood Management Works in Entire Country and River Management Activities and Works Related to Border Areas (2021-26) stresses on adopting less expensive non-structural measures like flood forecasting, flood plain zoning, flood proofing to accommodate high spat of water in majority of the places. It stresses on the use of advanced technology like artificial intelligence, satellites, remote sensing and GIS for flood forecasting and warning systems.

*Drought risk management***:** Location-specific rainfed technologies are available to cope with different drought situations. Much of the research done on rainfed agriculture in India relates to conservation of soil & rainwater and to drought proofing. The key technologies for drought mitigation are in situ moisture conservation, rainwater harvesting and recycling, resilient crops and cropping systems including contingency crop plans, foliar sprays, and integrated farming systems. The Mahatma Gandhi National Employment Guarantee Act (MNREGA) with an annual budget of $13 billion (2020) allocates 65 per cent its budget to natural resources management, water management, drought proofing, building grey and green infrastructure including nature-based solutions. A total of 344 crore person days employment generated; 4.29 crore assets has been geotagged to ensure the convergence of various drought management activities using geo-spatial techniques. Of the 12 crore who have been given MGNREGA cards, 11 crore have been linked to their Aadhaar cards and seven crore have linked to their bank cards. Indeed, this is a unique example of ensuring transparency and inclusion supported by geo-spatial and digital financial services; it bridges the gaps between pixel and the people and accelerates actions on managing drought risk through natural resources management and community empowerment.

*Building disaster and climate resilient infrastructure*: Infrastructure serves a community for a long time. Decisions on infrastructure investments taken now will have impacts over the decades and sometimes centuries to come. However, future conditions that may affect the infrastructure investment are deeply uncertain. Failure to manage these uncertainties could result in serious consequences. Hence, innovative geospatial methodologies and the climate models to deal with these uncertainties and make robust decisions for long term investments in a changing world must be applied. India has launched an ambitious $1.3 trillion plan to develop integrated infrastructure for the next 25 years. Popularly known as Prime Minister Gati Shakti (the power of speed), this is essentially to promote next-generation infrastructure. Assuming that the cost of resilience is in the range of 5 to 10 per cent of the cost of building infrastructure, it will be a significant investment in India's resilient future. India's leadership in the Coalition for Disaster Resilient Infrastructure (CDRI) is also an effort that addresses the multifaceted issues posed by vulnerability of infrastructure systems globally.

*Post-Disaster Needs Assessment (PDNA):* This is an internationally accepted methodology for determining the physical damages, economic losses, and costs of meeting recovery needs after a natural disaster through a government-led process. This compelling, interactive and sequential learning and training on PDNA with geo-spatial tools and techniques shall help the students support the initiatives of post-disaster rapid assessment of damage and losses for humanitarian assistance, recovery and reconstruction.

*Promoting climate action:* The National Action Plan on Climate Change (NAPCC) and the State Action Plan for Climate Change (SAPCC) have specific focus on the climate adaptation programmes. Policy coherence among the Climate Change Action Plans and the Nation Disaster Management Plan that strengthen India's position at the Voluntary National Review of the SDG progress, the Nationally Determined Contributions under the Paris Climate Change Agreement, and the Sendai Framework targets is a key determinant of India's adaptation and resilience pathways in a riskier world. Geospatial risk analytics play a key role in enabling climate actions through its adaptation and resilience tracks. In this regard, the National Mission for Sustainable Agriculture [NMSA] architecture enables converging, consolidating and subsuming all ongoing as well as newly proposed activities/programmes related to soil & water conservation, water use efficiency, soil health management and rainfed area development. NMSA promotes adoption of sustainable development pathway by progressively shifting to environmentally friendly technologies, adoption of energy efficient equipment, conservation of natural resources, integrated farming, etc.

In responding to the need to protect our farmers against the adverse effects of climate change, government as well as private crop insurers have been able to develop the necessary insurance framework which will help the farmers if they are to face the brunt of a natural disasters. India had already joined the group of top five countries in terms of crop insurance market and technology platforms providing solutions to address lower rate of subscription to farmer benefits. In the current times, startups have penetrated throughout the farming value chain. In the recent years, with application of new age technologies like blockchain and AI in the farming ecosystem, entrepreneurs have been able to provide farmers with advanced and futuristic solutions to improve their output. Usage of such advanced technologies have also provided the startups with new funding opportunities as they are now trying to concentrate and solve the major challenges that the farmers community will face due to climatic changes.

Climate risk is becoming increasingly compounded, interconnected and interacting, causing shifts in the frequency and intensity of hazards. The urgency and importance of resilience in agriculture requires bridging persistent knowledge gaps and fostering a better understanding of how agriculture is affected by extreme climate and weather events.

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# Extreme Weather Events in India

**Kamaljit Ray**

*Advisor/Sc-G, Ministry of Earth Sciences, New Delhi*
*Email: raykamaljit@gmail.com*

## Introduction

India is vulnerable to impacts of climate change owing to its diverse climate and topography. Extreme weather events like heat waves, cold waves, cyclones, floods, lightning etc. have affected various regions of Indian subcontinent and it appears that the number of such events have increased significantly over the years. Many researchers have reported an increase in the annual average number of extreme events in the past 50 years. There has been a significant rising trend in the frequency and magnitude of extreme rain events in many regions over India particularly during the South-west monsoonal rainfall. This increase has led to the increase of flood events during the monsoon period in the recent decades. Floods attributed to extreme rain events in India alone have led to losses of around 3 billion dollars per year (almost 10% of global economic losses).

The Global mean surface temperature anomaly during 2021 (January to September as per State of the Global Climate 2021 WMO provisional statement) was about 1.08 ±0.13 °C above the 1850-1900 pre-industrial average. During 2021, five tropical cyclones formed over the north Indian Ocean with three forming over the Bay of Bengal and 2 forming over the Arabian Sea. In addition to these, extreme weather events like floods, landslide, lightning, thunderstorm, were also experienced in various parts of the country (Fig.1).

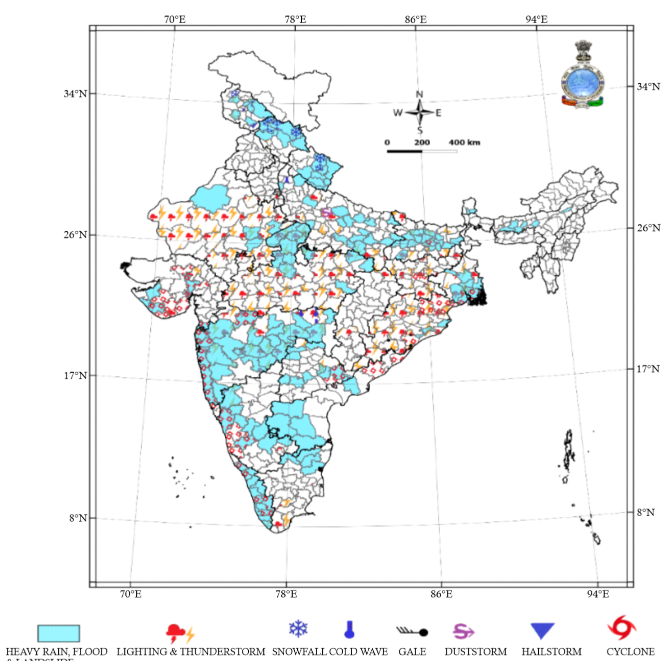


**Fig. 1.** Extreme Weather Events 2021

In 2021, five cyclones formed over the North Indian Ocean. Among these 5 cyclones, the most devastating was Extremely Severe Cyclonic Storm TAUKTAE (14 May to 19 May) which formed in the pre-monsoon season over the Arabian Sea, crossed Saurashtra coast on 17$^{th}$ May, claiming 144 lives from across the states in western India stretching from Kerala to Gujarat. The human mortality due to each of these extreme events based on the media and the government reports from disaster Management Authorities can be seen in Fig. 2. Maharashtra was most adversely affected state during 2021, which reportedly claimed more than 340 deaths mainly due to extremely heavy rainfall, floods, landslide, lightning, cyclonic storms and cold-wave events.

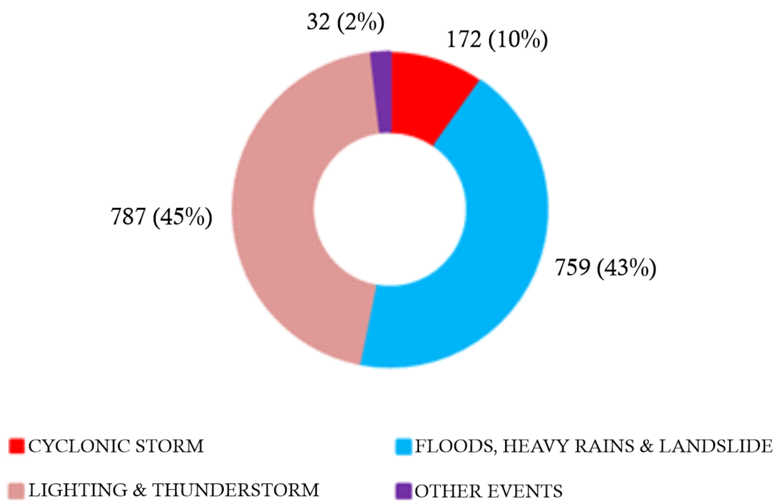


**Fig. 2.** Distribution of deaths & its percentage during 2021 for impacted weather events

## Mortality from Extreme Weather events

In-spite of the increase in the number of events in the past decades, the extreme weather events are known to contribute only 0.06% to the global mortality. The extreme weather events are reported better than in the past and globally mortality attributed to them has declined by 93 to 98%, despite the increase in the population at risk. But what matters is not the incidence of extreme weather events, but the impact of such events, especially the human impact. Aggregate mortality attributed to all extreme weather events globally has declined by more than 90% since the 1920s, in spite of a four-fold rise in population and much more complete reporting of such events. The aggregate mortality rate declined by 98%, largely due to decreased mortality in three main areas: Deaths and death rates from droughts, which were responsible for approximately 60% of cumulative deaths due to extreme weather events from 1900–2010, are more than 99.9% lower than in the 1920s. Deaths and death rates for floods, responsible for over 30% of cumulative extreme weather deaths, have declined by over 98% since the 1930s. Deaths and death rates for storms (i.e. hurricanes, cyclones, tornados, typhoons), responsible for around 7% of extreme weather deaths from 1900–2008, has declined by more than 55% since the 1970s. The decreases in the numbers of deaths and death rates reflect a remarkable improvement in society's adaptive capacity, likely due to greater wealth and better technology.

Scientific evidence suggests that climate change will increase the upward trend in the numbers of floods and storms worldwide, while the population requiring protection can be expected to increase at the same rate as population growth in disaster-prone regions. On the positive side, weather forecasting has made extraordinary progress in recent years, with predictions now highly reliable within a 48-hour period. In the face of climate change, we may not be able to stem the increased frequency of extreme events, but better risk management and mitigation could reduce deaths tolls and other heavy losses from these predictable hazards.

In recent years, national preparedness and more efficient responses to disasters have significantly reduced the numbers of people dying from weather-related hazards. For India, a key trigger was the 1999 cyclone which claimed around 10,000 lives in Odisha State while the casualties in two recent major cyclones were minimal.

For the country as a whole, the floods and tropical cyclones have been two major disasters causing mortality, though heatwaves and lightning are gaining importance. There is a significant increase in the EWEs in the last 50 years, except for cyclones (Fig. 3). In the past 50 years (1970-2019) a total of 7000 events were recorded with at least one death reported. Floods contributed maximum of 44.6% of the events followed by lightning with 36% contribution. Heat waves and cold waves contributed 10% and 7.8%, while Tropical Cyclone events were 1.6% of the total events. A yearly trend of the total number of extreme events and annual human deaths indicate a significant increase in the number of extreme events while the mortality numbers do not indicate any trend or pattern. The mortality graph shows four prominent peaks during the Odisha cyclone in 1971, Andhra Pradesh Cyclone in 1977, Odisha Super cyclone in 1999 and the Uttarakhand Floods in 2013.

The decadal analysis for five decades showed that, despite the significant increase in EWEs, there was a decrease in mortality rate due to total EWEs in each of the last two decades as compared to the earlier decade (Fig. 4). Decadal analysis of the human causalities indicates mortality due to the extreme events was maximum in the decade 1990-1999 (85% deaths were due to floods and cyclonic storms) followed by 1970-1979. These were the decades of three most important tropical cyclones which led to high mortality during that period.

The deaths/year for floods, the most important category linked to mortality, has been increasing by 3-5% in each decade during the period 1980-2009 (Fig. 5). It has decreased by 20% in the last decade, in-spite of the increase in the total flood events. The contribution of deaths due to floods is

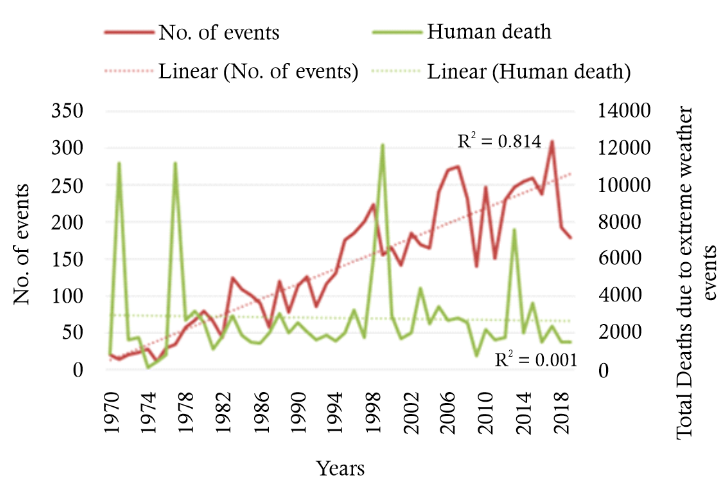


**Fig. 3.** Year-wise number of extreme weather events (EWE) vis-à-vis number deaths due to EWE, at all India Level

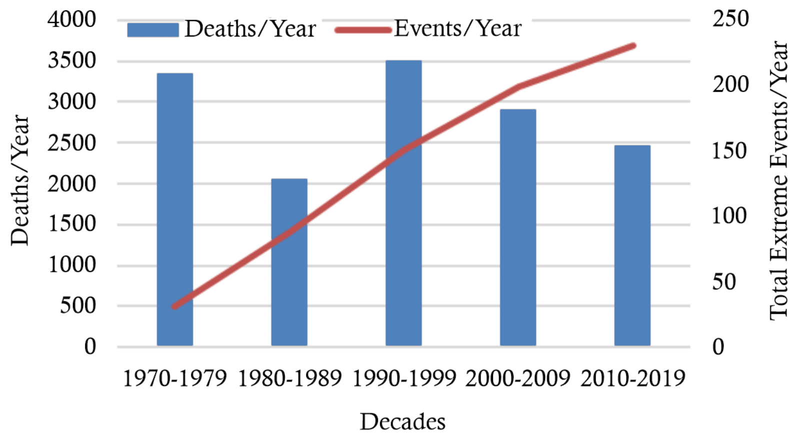


**Fig. 4.** Deaths/Year and Events/Year during the period 1970-2019 due to all EWEs

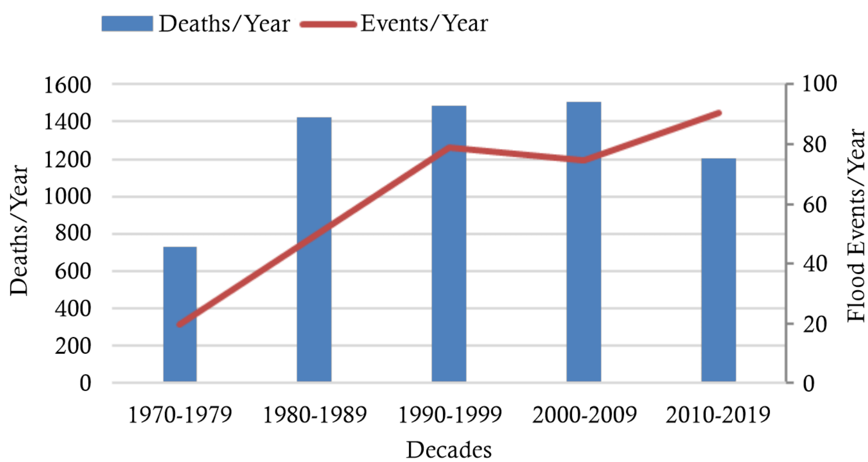


**Fig. 5.** Deaths/Year and Events/Year during the period 1970-2019 due to floods

highest in all decades except for the first decade (1970-1979), when tropical cyclones were responsible for highest mortality. In case of cyclones, the second most important category, the death rate peaked in 1970-1979 with another peak in 1990-1999.The death rate has decreased by almost 86% in the last decade (2010-2019) in comparison to earlier decade (2000-2009) and by 96% as compared to 1990-1999 (Fig. 6). The number of average events per year show a slight increase (2.0) as compared to earlier decade (1.7) but the average number of cyclones per year is showing a decreasing trend in the past 50 years. Improvement in weather models and early warning and better coordination with disaster management agencies could be one of the main reasons responsible in decreasing the calamities due to tropical cyclones by almost 90% as compared to any other extreme weather event after 2000. Fig. 7 shows that for heat waves, the 3$^{rd}$ most important category responsible for deaths due to extreme weather events, the deaths per year have increased by almost 47.5% in 2010-2019 as compared to 2000-2009. 57% of the total deaths due to heat waves have occurred after 2000. There has been a proportionate increase in the number of heat wave events by 24%. The warming of the tropical Indian Ocean and more frequent El Nino events in future may further lead to more frequent and longer heat wave episodes over India.

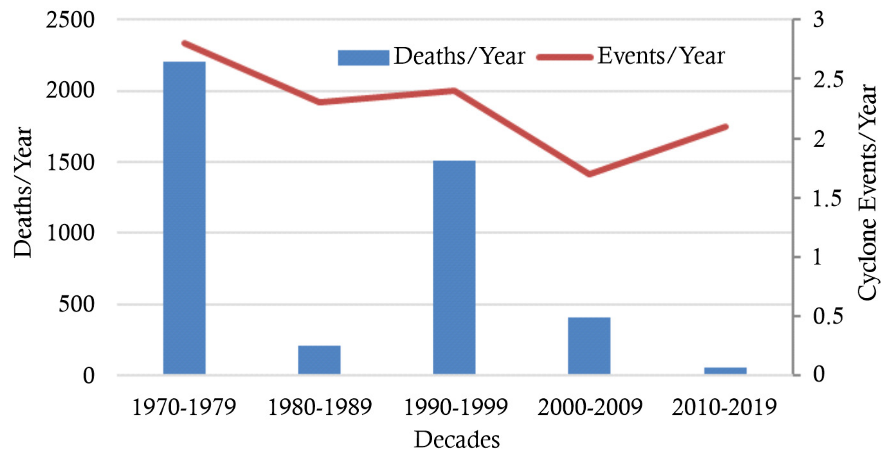


**Fig. 6.** Deaths/Year and Events/Year during the period 1970-2019 due to tropical cyclones

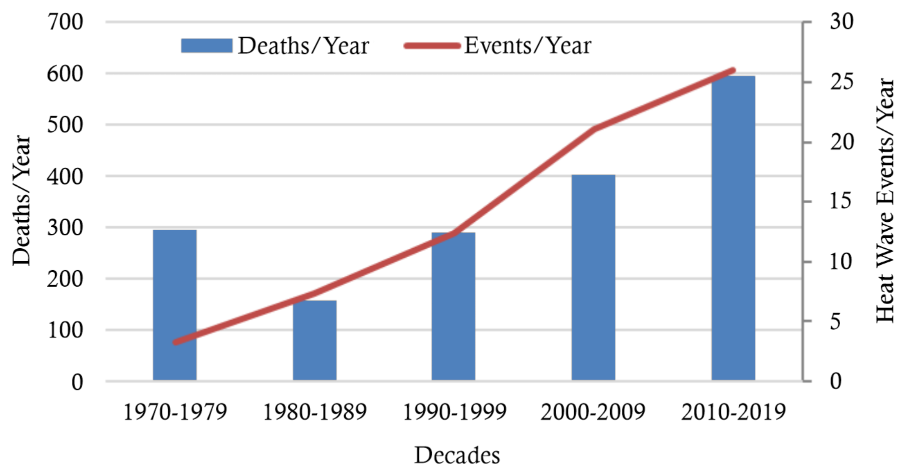


**Fig. 7.** Deaths/Year and Events/Year during the period 1970-2019 due to heat waves

## Mortality from Extreme Weather Events in Various States

State wise data of human casualties due to various extreme weather events was also analysed so as to get some hotspots responsible for various events. The highest number of deaths/million/year in the past 20 years were reported from Andhra Pradesh, followed by Odisha, Assam, Kerala and Maharashtra (Fig. 8). If we see event wise, Andhra Pradesh and Odisha reported highest causalities for cyclones, Andhra Pradesh reported highest numbers for Heat Waves; Kerala, Assam and Maharashtra reported highest casualties due to floods and Bihar and Jharkhand were responsible for highest deaths due to cold waves. Maharashtra and Odisha were highest in the category of Lightning events. Heat waves in 2015 took almost 2000 lives in Andhra Pradesh. Heat index in the ‘extreme danger’ category during 22-26$^{th}$ May, 2015 was responsible for claiming this many life in the region. In-spite of high temperatures and humidity, other variables like vulnerability due to lack of awareness, socio economic conditions, delayed medical treatment and over exposure due to outdoor activities play an important role in deciding the mortality due to heat waves. In India in the last two decades, the high population states like Andhra Pradesh, Bihar, Odisha, Assam, Maharashtra, Kerala, and West Bengal suffer from maximum mortalities by EWEs and there is a

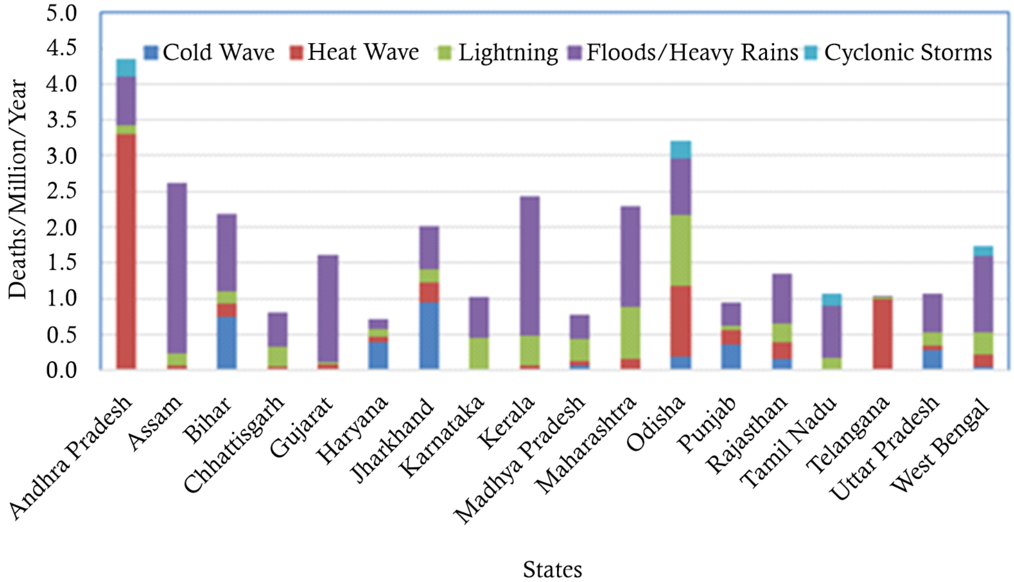


**Fig. 8.** State-wise and EWE wise distribution of mortality rates (deaths/year/million population) during 2000-2019, for states with a population of more than 15 million

need to prioritize these states for developing action plans for adaptation and mitigation in the coming times in order to counteract the effects of climate change.

## *Case Studies of Disasters linked to high casualties in the last two decades*

### *1) Odisha Super Cyclone*

It was one of the deadliest cyclones that hit Odisha Coast on 29th October, 1999. The cyclone led to more than 10,000 deaths and heavy damage and devastation along the coastal districts of Odisha and adjoining districts in West Bengal. Storm surge of 9 m and above astronomical tide was reported at Paradip port leading to inundation up to 35 km from the coast. The estimated central pressure was around 912hPa. The death rates have come down drastically for the cyclones that have hit Indian coasts in the 21st Century.

### *2) Extremely Heavy rains in Uttarakhand*

The highest number of deaths reported in floods due to heavy rains was around 5,000 in the Uttarakhand rains during 14-18 June, 2013. The floods led to massive landslides, avalanches and lake burst in Uttarakhand. Around 5000 people, including locals, pilgrims, tourists died and many were missing. More than 10,000 livestock also perished during this disaster. Next highest mortality causing events were 1,200 deaths reported in floods due to heavy rains in Mumbai (Maharashtra) in July 2005 and 1,267 deaths in West Bengal torrential rains in September 2000.

### *3) Heat wave in Andhra Pradesh and Telangana*

In 2015, heat waves prevailed over Eastern and Peninsular parts of the country and claimed human lives of over 2000 in Andhra Pradesh and Telangana. Andhra Pradesh (including Telangana) has been the hot spot of heat waves as per the data. The 500 deaths were reported in 1970, followed by 521 in 1998, 600 in 2002, 1300 in 2003 and 1200 in 2013. During 1986-1993, the heat waves that occurred over Andhra Pradesh were of lesser intensity and lesser duration but from 1994 onwards the frequency as well as the duration of heat wave spells has increased significantly.

### *4) Cold Wave in Bihar & Jharkhand*

Bihar and Jharkhand reported 288 and 295 deaths, each, in 2011.This was the highest number of deaths reported after 2000, due to cold waves. The highest in the last 50 years was 477 deaths reported in 1985 in Bihar. Bihar can be called as the hot spot of cold waves considering highest mortality rate (deaths/year) of 78 in the past two decades.

### *5) Lightning in Maharashtra*

Reporting of lightning in various states was very less in the earlier decades but it has increased significantly in the last two decades. After the year 2000, the highest mortality rates due to lightning strikes are in Maharashtra. Lightning reporting has improved in the last two decades. One of the reasons could be advances in telecommunication, media and declaring lightning as one of the disaster emergencies.

## *Infrastructure damage due to extreme weather events*

Globally, EM-DAT recorded 87 million homes damaged or destroyed by weather related disasters since 1995, plus 130,000 damaged or destroyed schools, clinics, hospitals and other critical health and education facilities. Floods and storms together accounted for around 98% of houses damaged and 99.9% of education health and education facilities. Cyclone Sidr destroyed more than 4,000 schools in Bangladesh in 2007; Peru lost 600 health facilities in one cyclone in 1997, while the tropical cyclone in 1999 devastated 11,000 schools in Odisha. More recently in April 2015, a flood in Peru damaged 614 schools and more than 17,000 houses. In 2015, Bangladesh was hit by two storms in April and June that respectively destroyed 29,000 and 33,000 homes. Given the importance of health and education for future development, high priority is given to national and international efforts to protect these facilities from disaster damage, especially in the developing countries. Preparedness and response planning would also be helped by a better understanding of the impact of poor building practices on disaster mortality figures. DRR managers could then compare this quantified data with the effectiveness of evacuation procedures, and allocate resources to the response measures most likely to save lives. In 1999, the super cyclone (Cyclone 05B) that struck Odisha, directly affected 15 million people and more than 2 million households. The shock of this event led to a strong government commitment to improve disaster resilience and risk reduction. The Odisha State Disaster Management Authority (OSDMA) was established in 1999, and helped to institutionalise DRR in Odisha. The Disaster Management Act was then passed in 2005 and since then, support has focused on early warning, disaster preparation, building shelters, planning evacuations, strengthening embankments, and conducting drills. The impact of this commitment to improve disaster risk reduction was evident when Cyclone Phailin struck the state in 2013. Due to a more accurate early warning about landfall given by India Meteorological Department and state's preparedness, impacts were significantly reduced with the deaths of 38 people, compared to more than 10,000 in the aftermath of the 1999 cyclone.

Ministry of Earth Sciences in addition to other programmes, focuses on predicting weather/ climate extremes and development of climatic applications based on monsoon forecasts, especially in the field of agriculture, hydrology and energy sector. The focus has been the high-resolution short-range predictions, predicting extremes, and using forecasts to develop applications for advisories and services to agriculture, hydrology, disaster management, energy sector, etc. As a new initiative to predict extremes, dynamical prediction of thunderstorm and lightning has been initiated. Model development, through enhancement in resolution and improvement in physical processes in the model, is a continuous process undertaken under Umbrella Scheme 'Atmosphere & Climate Research-Modeling Observing Systems & Services (ACROSS).

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# Role of Weather-based Advisories in Smart Agriculture in India

**K.K. Singh**

*Additional Director General (Meteorology) & Head, AAS Division*
*India Meteorological Department, Lodi Road, New Delhi-110003*
*Email: kksingh2022@gmail.com*

**ABSTRACT**

Weather and climate information plays a major role in the entire crop cycle right from selecting the most suitable crop/variety/ field preparation up to post harvest operations and marketing; and if provided in advance can be helpful in inspiring the farmer to organize and activate their own resources in order to reap the benefits by judicious application of costly inputs. Advancements in modern technology and their innovative applications in different sectors have brought a revolution in the way farming is practiced today in many parts of the world, and the developing nations are now adopting technology-led solutions to make agriculture sustainable. India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) in collaboration with Indian Council of Agriculture Research (ICAR) and State Agriculture Universities (SAUs) and IITs is rendering weather forecast based District/Block level Agrometeorological Advisory Service (AAS) for benefits of farmers in the country under the scheme "Gramin Krishi Mausam Sewa (GKMS)". AAS provides advance weather information along with crop specific agromet advisories to the farming community by using state of the art instruments and technology through efficient delivering mechanism of the information which ultimately enables farmers to take appropriate actions at farm level. This present system of delivering the services at district level is underway to extend up to sub-district/ block level with dissemination up to village level to meet the end users' requirements.

The various components of GKMS service delivery viz. observing weather, its monitoring and forecast; crop specific advisory bulletin generation; outreach and feedback are being digitized to support integrating all the components of information generation and action suggested linked to these information. An agromet Decision Support System (DSS) is being developed for preparing weather based advisories separately to build customised services to meet the needs of farmers. This includes a dynamic framework to link the existing knowledge base on crop, soil, crop weather calendar etc. generated to translate weather forecast into actionable farm advisories for efficient decision making. High resolution weather forecast data of GFS-T1534 at 12.5 km and extended range outlook for subsequent days is the used for advisory preparation. The bulletin will incorporate various satellite and model derived product of grid level such as soil moisture, crop GDD information, pest forewarning etc. and their amalgamation with weather forecast to assist farmers in taking management decisions.

**Key words:** Agromet advisory, digitations of information, weather smart farming

## Introduction

In agriculture, the crop production dynamics are influenced by multiple factors such as the type of the soil, crop variety, location, and weather and management practices. To improve crop productivity, farmers need integrated farm advice that consists of advice for crop protection and production problems, and appropriate risk mitigation measures. In recent past occurrence of extreme weather events such as cold waves, heat waves, hailstorms, thunderstorms and dust storms, drought and failure of rains have occurred unprecedentedly in India. Increased frequency of extreme weather events and occurrence of natural disaster could lead to crop failure and economic loss to the farmers (Swaminathan *et al.*, 2016). Weather and climatic information plays a major role before and during the cropping season and if provided in advance can be helpful in inspiring the farmer to organize and activate their own resources in order to reap the benefits. Due to recent advances in science and technology, it is now possible to forecast the occurrence of extreme events and the nature of devastation that may cause with greater degree of accuracy and with longer lead time (Siva Kumar *et al.*, 2005). Weather based Agromet advisory Services to the farmer have the potential to reduce the weather aberration associated losses to a large extent by suitable adoptive measure of dissemination to the farmer and planners community (Rathore *et al.*, 2009). In the present paper it is discussed that how the finer resolution weather forecast, satellite derived products, experts knowledge and amalgamation of new technologies in the advisory generation and dissemination enhanced the decision taking ability of the farmers and contributes in profitable farming. These initiatives will lead to help achieve the aims of Climate-Smart Agriculture (CSA) viz. increased productivity, enhanced resilience, reduced emissions.

## Existing Agromet Advisory Services

To render the need of weather information to farming community efforts has been made since 1945 with the initiation of Farmers Weather Bulletin. Since then with the advent of technology, expansion of weather observation network and weather forecast the customized weather information in the form of advisory also followed era of evolution. Agro advisory Services initiated at state level in the year 1976 was followed by Agro-climatic zone level service using medium range weather forecast in the year 1991. In the year 2008 district level agro advisories was initiated by IMD, MoES in collaboration with ICAR and State Agriculture Universities etc. Thereafter, continuous efforts are being made to generate weather forecast at even finer scale along with appropriate agromet advisories. Thus, since 2018, weather forecasts are being generated at block level for next five days along with block level agromet advisories for selected blocks. Presently agromet advisories are being prepared on every Tuesday and Friday for all the agriculturally important districts and around 3100 blocks by 130 Agromet Field Units (AMFUs) and 199 District Agromet Units (DAMUs) in the country. The main emphasis of the existing AAS system is to collect and organize climate/weather, soil and crop information, and to amalgamate them with weather forecast to assist farmers in taking management decisions. This has helped to develop and apply operational tools to manage weather related uncertainties through agro-meteorological applications for efficient agriculture in rapidly changing environments.

## Weather Forecast

IMD is having different kinds of network of observatories in India to monitor the weather and climate which are Conventional Observational Network, Automatic Weather Stations (AWS), Agro-AWS, Buoy/ Ship Observations, Cyclone Detection Radars, Doppler Weather Radars and Satellites observations etc. These observations are now being used to run its global and regional numerical prediction models on High Performance Computing Systems (HPCS). IMD has established an observational network covering different parts of the country and further augmentation is progressing for extensive weather observation acquisition and collection platform to supplement the existing infrastructure.

IMD has implemented now casting of thunderstorms, squalls and hailstorms which are issued by Regional Meteorological Centers and Meteorological centers of IMD. Three hour prior information about the weather event is useful for the farming community about the occurrence of the adverse weather.

Medium range forecast for next 10 days, issued for 8 weather parameters *viz.*, rainfall, maximum temperature, minimum temperatures, wind speed, wind direction, relative humidity I, II and cloudiness. This weather forecast is prepared using the GFS-1534 at 12.5 km spatial resolution. Under GKMS scheme for preparation AAS, Medium Range Weather Forecast of next 5 days has been generated on Every Tuesday and Friday by NWP division of IMD and sent to RMC/MC for value addition in forecast by local expertise. Value added district-wise and Block level forecast further disseminated to AMFUs & DAMUs for Agroadvisory generation. Group of experts in agriculture discipline issues the advisory for next five days based on the forecast. Medium Range Weather forecast is of prime importance for farmers in order to take the tactical decisions. Farmers are using these advisories for sowing and transplantation of crops, fertilizer application, predictions regarding pests and diseases and measures to control them, weeding/thinning, irrigation (quantities and timing), and harvest of crops.

In addition to Now casts and Medium range forecast integration of extended range forecast based outlook in agromet advisory also started since monsoon 2020. The extended range forecasting fills the gap between medium-range weather forecasting and seasonal forecasting. Suite of models from CFSv2 coupled model is used for generating operational Extended Range Forecast products to different users. IMD jointly with ICAR-CRIDA started National Agromet Advisory bulletins based on Extended Range Weather Forecast during southwest monsoon 2013 to fulfil the needs of farmers and other users. Bulletin was prepared and issued by ICAR-CRIDA for the next fortnight with update on every Friday.

## Customized Agromet products for advisory preparation and an integrated platform Agromet Decision Support System for Advisory Preparation

Initial step to help the smart farming is preparation of products or platform which will help the farmers in decision making. With this objective under GKMS System various products are generated using weather forecast, satellite observation, remote sensing data, gridded weather data for monitoring and forecasting of soil moisture, drought and crop health, different rainfall indices. Aridity anomaly maps gives information about the moisture stress experienced by growing plant. The crop water stress condition during the monsoon anomalies are helpful for early warning of crop stress occurrence. Standardized Precipitation Index (SPI) (Guttman, 1999; Guhathakurta *et al.*, 2011) used for monitoring rainfall departure status from the normal and helps in monitoring of rainfall status. Satellite derived weekly Normalized Difference Vegetation Index (NDVI) monitors the crop condition. These entire derived products guide advisory in decision making. India Meteorological Department in collaboration with Regional Integrated Multi-Hazard Early Warning System (RIMES), Thailand developed a decision support system named Agromet-Decision Support System (Agro-DSS: agromet.imd.gov.in), the provision for exchange of weather information and automation of district/block level advisory preparation. Agro-DSS is a web-based platform to integrate the multi-level process of advisory preparation and its automation to enhance the efficiency of system. The broad initiative of developing Agromet-DSS is to automate all the process of advisory preparation and to provide various Agromet product to help the decision maker in advisory preparation such as availability of direct model output and their value addition at respective state units of IMD, Disseminating the value added forecast to AMFUs/DAMUs under stipulated timeframe in order to enhance the efficiency of system, providing short, medium and extended range forecast on single platform at different spatial scale, populating database of location specific crop information to help in advisory preparation, platform for district/block level advisory preparation by respective AMFUs and DAMUs. The system is enabled with the facility of real time flow of direct model forecast and observed weather data through network of observatories at centrally located server. Hence, DSS facilitates real time as well as monthly and seasonal scale forecast validation and report generation; collection, analysis and integration of district/block specific soil and crop information to be integrated in dynamic crop calendar. Digitization of linking crop calendar with weather forecast to accurately assess the weather impact on crop is under development.

## Agromet Advisory Preparation

District and block level Agromet advisory bulletin has been prepared at AMFU level using the weather forecast of IMD. Figure 1 shows Agromet Advisory Services System currently being followed under GKMS scheme to prepare district and block level agromet advisory bulletin. Inter-disciplinary group of agricultural and extension specialists at AMFUs formulates weather based farm advisory bulletin (Singh, 2016). These bulletins contain location-specific and crop specific farm level advisories tailored to meet the farmers' need. The bulletins are encoded in a format and language which is easy to comprehend by the farmer in his decision making processes. The Agromet Advisory Bulletins are issued at district, state and national levels to cater the needs of local level to national level. The State Level bulletin is a composite of district bulletins helping to identify the distressed district of the state as well as plan the supply of appropriate farm inputs such as seeds, irrigation water, fertilizer, pesticides etc. These bulletins are jointly prepared by State Meteorological Centre (MCs) of IMD and AMFUs and mainly used by State Government functionaries. National Agromet Advisory Bulletins are prepared by National Agromet Advisory Service Centre, IMD, using inputs from various states. This bulletin helps to identify stress on various crops for different regions of the country and suitably incorporate advisories. Ministry of Agriculture is prime user of these bulletins, which help take important decisions in Crop Weather Watch Group (CWWG) meetings at national level. The bulletins are also used by a large number of other agencies including fertilizer, pesticide industries.

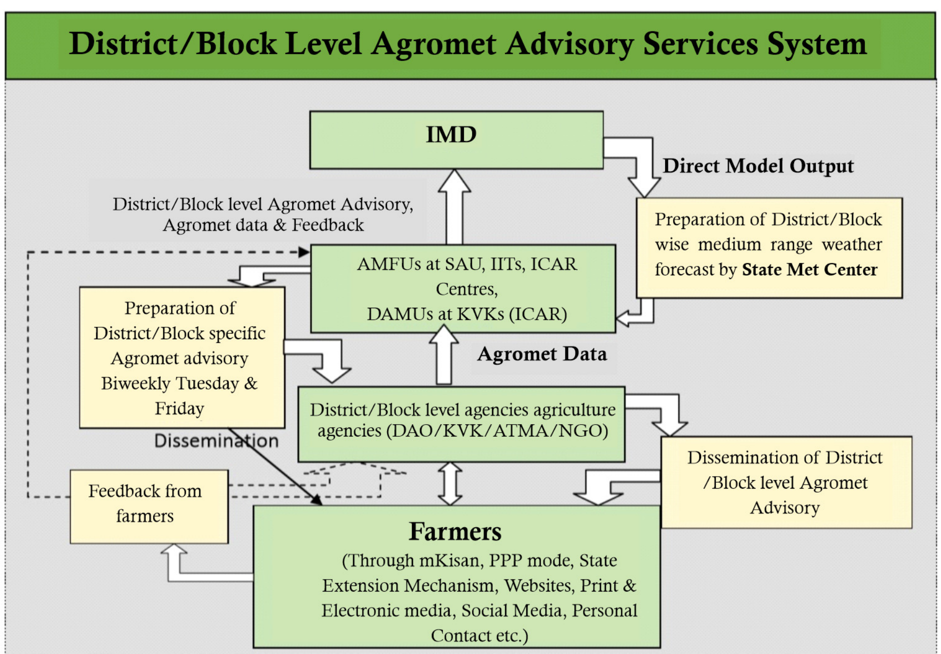


**Fig. 1.** Flowchart showing Agromet Advisory Services System at district and block level

## Dissemination of Agromet Advisory Bulletin

GKMS are transmitted to the end-users using all possible modes of communication, including conventional and advanced methods of communications viz., personal contacts, social media, and print and electronic media. These advisory bulletins are being broadcasted through various new papers, the DD Kisan channel, Regional DD centres, Private TV Channels, and radio. Different messaging apps such as WhatsApp are extensively used to disseminate farm advisories to the farmers. Till now, more than 14000 WhatsApp groups have been created, covering more than 1 lack villages and 11 lack farmers. Various private organizations such as Reliance Foundation, Tata Consultancy Services, IFFCO Sanchar Ltd. and different NGOs have also partnered to disseminate these advisories through their own networks.

***Strategies for expansion and improvement of services to support climate smart agriculture:*** To further strengthen the AAS in the country in terms of observation, seamless weather forecast, manpower, real time information flow, research and development (R&D), dissemination etc. the major activities are as follows:

- Soil moisture and soil temperature monitoring, estimation and validation;
- Generation of land-based and satellite-based agro-met products;
- A dynamic crop weather calendar system for major crops.
- Development of micro-level weather forecast for agriculture,
- DSS for crop and location-specific Pest & disease forewarning
- AI & ML based decision support system for personalized service to farmers;
- Development of climatic risk matrix tools for different crops for application of extended range/ seasonal forecast.

## Conclusion

The risks confronting with agriculture production are very high due to weather and climate variability. Weather forecast translated in agro advisory helps in taking the decision at field level in advance and avoids the associated risk. Increasing number of observatories, use of advance tools and techniques, expansion of existing Agromet Field Unit network, customized Decision Support System for advisory generation and advance dissemination tools & techniques are highly efficient to support the climate smart agriculture under existing scenario of digitization of information.

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# Scope of Organic Farming in India

**Yashbir Singh Shivay**

*Division of Agronomy, ICAR–Indian Agricultural Research Institute, New Delhi-110 012*
*Email: ysshivay@gmail.com*

## Introduction

Organic products are grown under a system of agriculture without the use of chemical fertilizers and pesticides with an environmentally and socially responsible approach. This is a method of farming that works at grass root level preserving the reproductive and regenerative capacity of the soil, good plant nutrition, and sound soil management, produces nutritious food rich in vitality which has resistance to diseases. Organic farming in India has been reinvented and getting more popularity with each passing day. Farmers, entrepreneurs, researchers, administrators, policy makers and of course consumers are showing increasingly greater interest in promotion and development of organic farming in the country. Organic food products are considered to be much safer and nutritious than the products produced by the conventional farming. Organic farming also helps to restore the soil health, protect environment, enhance biodiversity, sustain crop productivity and enhance farmers' income. Seeing the long-term benefits of organic farming, the Government of India has taken many important steps for its promotion in the country. With the support of all kinds of stakeholders and the Government, the scope of organic farming movement has widened tremendously in India.

## Growth

At present, organic farming is practiced in 187 countries at about 72.3 million hectares of agricultural land, which is managed by at least 3.1 million farmers (2021). The market research company 'Organic Monitor' estimated the global market for organic food to have reached 81.6 billion US dollars in 2015. Further, according to the research study, the global Organic Food and Beverages Market was estimated at USD 220.0 Billion in 2019 and is expected to reach USD 620.0 Billion by 2026. The global Organic Food and Beverages Market is expected to grow at a compound annual growth rate (CAGR) of 16% from 2019 to 2026. As per the available statistics, India's rank 8$^{th}$ in terms of World's Organic Agricultural land and 1$^{st}$ in terms of total number of producers as per 2020 data (Source: FIBL & IFOAM Year Book, 2020). This is mainly because of small land holdings with each producer. The data on organic production and area in India is given in Table 1.

In recent years, there has been a considerable increase in certified cultivated area in the country. It has increased from a meagre 0.24 million hectares in 2010–11 to 1.49 million hectares in 2015–16, an over 6-fold increase in five years. Similarly, the certified area (including cultivated and wild harvest area) under organic farming has grown from 4.43 million hectares in 2010–11 to 5.71 million hectares in 2015–16, a 28.9% increase in five years. The organic production has also increased in almost same proportion as increase in area under organic cultivation in recent years. For example, the total certified production (including cultivated and wild harvest area) under organic farming has increased from 0.69 million tonnes in 2011–12 to 1.35 million tonnes in 2015–16, almost two-fold

**Table 1.** Total certified production, total area and cultivated area under organic farming in India (APEDA and NCOF)

| Year | 2010–11 | 2011–12 | 2012–13 | 2013–14 | 2014–15 | 2015–16 | 2017–18 | 2018–19 | 2019–20 |
|---|---|---|---|---|---|---|---|---|---|
| Total production (million tonnes) | 3.88 | 0.69 | 1.34 | 1.24 | 1.10 | 1.35 | 1.70 | 2.64 | 2.75 |
| Total area under certification (including wild harvest, million ha) | 4.43 | 5.55 | 5.21 | 4.72 | 4.90 | 5.71 | 3.56 | 3.43 | 3.67 |
| Total area under certified organic cultivation (million ha) | 0.24 | 1.08 | 0.50 | 0.72 | 1.20 | 1.49 | 1.78 | 1.94 | 2.30 |
| Total area under certified wild harvest (million ha) | 4.19 | 4.47 | 4.71 | 3.99 | 3.70 | 4.22 | 1.78 | 1.49 | 1.37 |

increase in four years. Further, As on 31st March 2021 total area under organic certification process (registered under National Programme for Organic Production) is 4.339 million ha (2020–21). This includes 2.658 million ha cultivable area and another 1.681 million ha for wild harvest collection. Among all the states, Madhya Pradesh has covered largest area under organic certification followed by Rajasthan, Maharashtra, Chhattisgarh, Himachal Pradesh, Jammu & Kashmir and Karnataka.

At present, India produced around 3.497 million tonnes (2020–21) of certified organic products which includes all varieties of food products namely oil seeds, fibre, sugar cane, cereals & millets, cotton, pulses, aromatic & medicinal plants, tea, coffee, fruits, spices, dry fruits, vegetables, processed foods etc. The production is not limited to the edible sector but also produces organic cotton fiber, functional food products etc. (https://apeda.gov.in/apedawebsite/organic/Organic_Products). Among different states Madhya Pradesh is the largest producer followed by Maharashtra, Karnataka, Rajasthan and Uttar Pradesh. In terms of commodities oil seeds are the single largest category followed by sugar crops, cereals and millets, tea & coffee, fiber crops, fodder, pulses, medicinal/ herbal and aromatic plants and spices & condiments.

## Exports

The total volume of export during 2020–21 was 0.888 million tonnes. The organic food export realization was around to the tune of Rs. 707,849.52 lakhs (1,040.95 million USD). Organic products are exported to USA, European Union, Canada, Great Britain, Korea Republic, Israel, Switzerland, Ecuador, Vietnam, Australia etc. In terms of export value realization processed foods including soya meal (57%) lead among the products followed by oilseeds (9%), cereals and millets (7%), plantation crop products such as tea and coffee (6%), spices and condiments (5%), medicinal plants (5%), dry fruits (3%), sugar (3%) and others. (https://apeda.gov.in/apedawebsite/organic/ Organic_Products.).

## Government Schemes

In recent times, the Government of India has very actively supported the cause of organic farming movement in the country. It has opened new research and development centres and at the same time strengthened the existing ones. The Government has also launched several new schemes for the popularization of organic farming and equipping the farmers with the latest developments in this field. The first major step taken by the Government was implementation of the National Programme for Organic Production (NPOP) in the year 2001. The NPOP involved the accreditation programme for certification agencies, norms for organic production and promotion of organic farming in the country. Another big step taken by the Indian Government was establishment of the National Centre of Organic Farming (NCOF) in Ghaziabad (UP) in the year 2004. This centre has implemented the National Project on Organic Farming (NPOF) at Ghaziabad and its eight regional centres at Bangalore, Bhubaneswar, Panchkula, Ghaziabad, Imphal, Jabalpur, Nagpur and Patna. The NCOF is also responsible for implementation of the Participatory Guarantee System (PGS), a kind of free certification programme for organic farming, particularly suitable for domestic market. For online operation of PGS certification system, a web portal has also been started and can be accessed at www.pgsindia-ncof.gov.in.

The Government of India is promoting organic farming through different schemes or programmes also, such as, National Mission for Sustainable Agriculture (NMSA)/ Paramparagat Krishi Vikas Yojana (PKVY), Rashtriya Krishi Vikas Yojana (RKVY), Mission for Integrated Development of Horticulture (MIDH), National Mission on Oilseeds & Oil Palm (NMOOP), and Network Project on Organic Farming of ICAR. The Ministry of Agriculture & Farmers Welfare is promoting Organic Farming as a sub-component under NMSA. Under the scheme, financial assistance is provided for setting up of mechanized fruit and vegetable market wastes, agro wastes compost units and setting up of liquid carrier-based biofertilizer and biopesticide production units. The organic farming is also being promoted under Saansad Adarsh Gram Yojana in the selected villages adopted by the Hon'ble MPs in their respective constituencies.

The Indian Council of Agricultural Research (ICAR) has also launched a new research Institute named 'National Organic Farming Research Institute' (ICAR-NOFRI) in Gangtok (Sikkim) during 2016. The major mandate of this Institute is to conduct basic, strategic and adaptive research on efficient, economically viable and environmentally sustainable organic farming systems for improving productivity, resource use efficiencies and quality of produce. Another important step in the field of organic farming was the declaration of Sikkim as organic state by the Hon'ble Prime Minister of India, Shri Narendra Modi on 18$^{th}$ January 2016. Since then most of the north-eastern states are interested to promote organic farming in Sikkim way. Furthermore, a Central Sector Scheme namely, Mission Organic Value Chain Development for North Eastern Region has been launched for promoting organic farming in the North Eastern Region with an outlay of Rs. 400 crores for three years from 2015–16 to 2017–18. Recently on 1 February 2022, honourable Union Finance Minister, Smt. Nirmala Sitharaman Ji announced that chemical-free Natural Farming will be promoted throughout the country, with a focus on farmers' lands in 5-km wide corridors along river Ganga, at the first stage.

The Government of India is also focusing on increasing the area under organic farming in the country. This task is being achieved through Paramparagat Krishi Vikas Yojana (PKVY), launched by the Government in year 2015. The important aim of the PKVY was to form 10,000 clusters in three years and bring about five lakh acres of agricultural area under organic farming. Fifty or more farmers can form a cluster having 50-acre land to take up the organic farming under this scheme. Every farmer is being provided Rs. 20,000 per acre support for seed to harvesting of crops and to transport produce to the market. To increase the profit from organic crops, it is also important to grow them by scientific methods. In this direction, the ICAR's Network Project on Organic Farming, Modipuram (UP) is actively evolving the technology packages for cultivation of organic crops suitable for different parts of the country. Besides this, several other ICAR Institutes and State Agricultural Universities (SAU) are promoting organic farming through their research and extension activities.

To conduct research, teaching and extension activities in organic farming, the CSK Himachal Pradesh Agricultural University, Palampur has established a new 'Department of Organic Agriculture' in 2009 for the benefit of farmers and others concerned. On the same line, Punjab Agricultural University has also established a new 'School of Organic Agriculture' under the 'College of Agriculture' in 2017 to carry out multidisciplinary research, training and extension activities for the development and dissemination of scientific knowledge on organic and integrated agriculture. Thus the Central Government and many State Governments have provided excellent support to promote organic farming in the country.

## Opportunities

India has an inherent advantage in organic farming because of its diverse geography and climatic conditions. India has a great potential to increase its area under organic farming, particularly in rainfed/ dryland/ hill regions. Many such areas are organic by default and have low productivity as well. Research results have conclusively proved that these lands respond very well to the organic management. Hence, more of these areas should be used for organic cultivation, particularly in the light of the increase in drought frequency. A huge potential is also seen in the export and marketing of organic inputs and outputs (organic products). The opportunities for export are also expanding in the country. Simultaneously, the local demand for organic food is also growing. Organic products, which until now were mainly exported, are now finding consumers in the domestic market as well.

A great employment opportunity also exists in the organic sector. Unemployed people can find employment by producing and marketing the organic seed, organic manures (composts, vermicomposts), organic fertilizers, biofertilizers and organic pesticides (Shivay, 2007, 2011; Kumar and Shivay, 2014; Shivay and Kumar, 2019). One can easily set up the units for production of vermicompost, biofertilizers and organic pesticides and find self-employment. Several Government and Private Institutions are offering training opportunities, degrees and diplomas in the field of organic farming. The trainings are being offered in the field of production of vermicompost and biofertilizers, and of course, in the production, processing and marketing of organic products. Thus, people can train themselves in a specialized field and secure a suitable job.

## Constraints

The important constraints being faced by farmers and other stakeholders in the adoption and spread of organic farming in India are listed below:

1) Shortage of organic seeds.
2) Lack of efficient marketing system from farmer to consumer.
3) Lower crop yields in some cases.
4) Low income during transition/ conversion period hinders the spread of organic farming.
5) Non-availability of premium prices of organic products to the farmers.
6) Lack of technology packages for varying crop, soil and climatic conditions. More research is needed to develop eco-friendly techniques for management of weeds, insect-pests and diseases in organic production systems.

7) Limited availability of organic manures and biofertilizers.
8) Complexities in certification processes, like, PGS (Participatory Guarantee System) and third party certification.
9) Weak linkages among the organizations in the organic sector.
10) Lack of infrastructure.
11) High cost of certain inputs.

## Conclusion

With the increasing awareness of consumers about the safety and quality of organic foods, long-term sustainability of agricultural system and accumulating proofs of being equally productive, the organic farming is going to be adopted by more number of farmers. The domestic as well as international market is expanding at a much faster rate in recent times. Seeing the economic, social, health and environmental benefits of organic farming, the Government of India has supported it in a big way. A number of schemes and programmes are being supported by the Government for promotion of organic farming in the country. A great opportunity for employment of rural youth exists in production, processing and marketing of organic products and inputs. However, it is also important to overcome certain constraints being faced by farmers and other stakeholders in organic farming. Seeing the number of farmers involved in India and support by the Government, it can be easily realized that India is slowly but steadily moving towards organic farming.

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# Resource Conservation Measures for Enhancing Resource Use Efficiency and Productivity

**M. Madhu[1]*, K. Kannan[2] and H.C. Hombegowda[2]**

[1]*ICAR–Indian Institute of Soil and Water Conservation, Dehradun-248 195, Uttarakhand, India*
[2]*ICAR–Indian Institute of Soil and Water Conservation, Research Centre, Udhagamandalam-643 004, Tamil Nadu, India*
**Email: director.iiwm@icar.gov.in*

## Introduction

India is endowed with vast natural resources. However, it suffers from a variety of problems ranging from population explosion impacting accelerated land degradation. India homes over 16% of world's population in an area, which is 2.42% of global spread. Per capita arable land in India, which is around 0.15 ha at present, is expected to decrease to a meager of 0.09 ha by 2075. Land is a complex resource composed primarily of soil, water and biodiversity. The product of their interactions, ecosystem goods and services, is the foundation for sustainable livelihoods, social cohesion and economic growth. Communities and countries can no longer afford to squander this valuable resource. In a predominantly agricultural system, the objective of improving the productivity, profitability and prosperity of the farmers and achieving agricultural development on an ecologically sustainable basis can be attained only when conservation of the natural resources are assured. Due to lack of adequate information on soil resources coupled with improper land use planning resulted in many of the present day land degradation problems in our country such as salinity / alkalinity and water logging in command areas, severe erosion in catchments leading to siltation of reservoirs, decrease in productivity of crops etc. Efforts were made by various agencies to identify various types of degraded lands, their spatial extent and severity levels.

Further, water resources is also under increasing pressure in India due to the changing climate. Changes in climatic conditions will affect demand, supply and water quality. In regions that are currently sensitive to water stress (arid and semi–arid regions of India), any shortfall in water supply will enhance competition for water use for a wide range of economic, social and environmental applications. Evapotranspiration (ET) is the major component of hydrological cycle after precipitation and determines the crop water requirement. Any change in climatic parameters due to global warming will also affect evapotranspiration or crop water requirement. Eventual global warming would increase dry conditions in the world's arid regions by increasing potential evapotranspiration (Houerou and Le Houerou, 1993). The surface water and groundwater resources in India play vital roles in agriculture, fisheries, livestock production, forestry and industrial activity. Water and agriculture sectors in India are largely dependent on monsoon rainfall. There have been considerable spatial and temporal variations in rainwater availability in recent years as a result of an observed swing in the onset, continuity and withdrawal patterns of the monsoon. Agricultural output is primarily governed by availability of water, making the country's agrarian economy sensitive to the status of water resources and the monsoon. At present faring sector in India consumes 78% of the fresh water resources and 80% of this irrigation is for water guzzling crops such as rice, wheat and sugarcane. Water resources in India is adequate to meet its demand but crisis is due to its poor management, and is further challenged due to negative impact of climate change. As per OECD environmental outlook 2050, India would face severe water constrains by 2050 and that has implications on India's agriculture sector. Technologies such as conservative agriculture should be popularized, as it's known to increase water use efficiency.

## Land Degradation Status and its Geographical Distribution in the Country

The total degraded land in the country has been mapped at 91.21 M ha which is 27.77% of geographical extent of India during 2015-16 by the NRSC-ISRO (NRSC, 2019). The ministry of Environment and Climate Change reported, the economic loss was 3.17 lakh crore ($46.90 billion) in 2014–2015 financial year due to rapid land degradation. According to the Atlas prepared by NRSC on land degradation, water erosion is found to be dominant process in majority of the States. It is found to a maximum extent in Maharashtra (106.13 lakh ha) followed by Odisha (58.33 lakh ha) and Madhya Pradesh (56.30 lakh ha). Wind erosion is predominant in arid regions of India and found to be occurring over 138.05 lakh ha in Rajasthan (hot desert) as a dominant process followed by Jammu & Kashmir (cold desert) and Haryana. Waterlogging is found to be maximum in Bihar (7.11 lakh ha) followed by Uttar Pradesh (4.45 lakh ha) and Assam (2.68 lakh ha), whereas it's not observed in the States of Chhattisgarh, Maharashtra, Mizoram, Nagaland, Sikkim. It is observed to a lesser extent in Himachal Pradesh, Madhya Pradesh, Uttarakhand, Meghalaya, Tripura, Jharkhand, Goa, Jammu and Kashmir, Manipur, Karnataka, and Telangana in increasing order of area. Salinisation/alkalisation is a process found extensively in Gujarat (4.16% of total land degradation) followed by Uttar Pradesh (0.66%) and Rajasthan (0.58%).There is also significant extent of this process occurring in Andhra Pradesh, Tamil Nadu, Telangana, Maharashtra, Karnataka, Bihar, Haryana, Jammu & Kashmir, Madhya Pradesh, Punjab, Odisha, and Goa in decreasing order of area. Acidification process is dominant in Nagaland (7.43 lakh ha) followed by Manipur, Mizoram, Meghalaya, Arunachal Pradesh, Tamil Nadu, Tripura, Assam, Kerala in decreasing order of total area. This is mostly confined to high rainfall regions and is formed due to leaching of alkaline salts to lower depths. Glacial process is found mostly in cold desert areas of Jammu Kashmir (18.87 lakh ha), Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. The dominant degradation type is frost shattering as compared to frost heaving. The extent of land degradation due to anthropogenic activities is found maximum in Rajasthan, Karnataka, Andhra Pradesh, and Telangana, Maharashtra followed by Jharkhand, Madhya Pradesh and Chhattisgarh. Other land degradation processes such as barren rocky, mass movement and riverine sand is observed maximum in Jammu and Kashmir and Rajasthan, followed by Gujarat.

Development of these degraded lands is the only viable option to increase food production in India and to meet the requirements of growing population as well as restoring fragile ecosystems. Land degradation neutrality, is attaining paramount importance to compensate for the natural resources requirement ensuring sustainable land management. The translation of global targets into national ones, such as land degradation neutrality, will help position the interconnected challenges of desertification, soil erosion and drought at the centre of the conservation sector. It will provide impetus towards more integrated responses to climate change and the other major environmental crises of our time.

## Integrated Soil and Water Conservation Technologies

Integrated soil and water conservation is the use of soil and water management practices viz, *in-situ* moisture conservation methods, increasing soil health(physical, chemical and biological) carbon sequestration, runoff control, prevention of soil loss, cropping system, agro forestry and water harvesting to increase the productivity and income while maintain ecological function of soil. Integration of various components compliments each other and ensures effective trapping of runoff, increase filtration soil moisture content and productivity.

## *In-situ* Moisture Conservation Measures

### *Tillage and land configuration*

Land and water are closely inter connected and consequently they influence land productivity, therefore, land management techniques that encourage more rainfall to enter the soil are key strategies for improving productivity of rain-fed systems. The soil moisture content in the root zone during the crop growing period in these regions appreciably affects crop growth, development and the overall land productivity especially in semi arid regions. Tillage roughens the soil surface and breaks any soil crust. This leads to increased water storage by increased infiltration. Deep tillage might be a tool to make crops more resilient to climate change and mitigate yield losses caused by droughts. However, response to tillage varies with rainfall, soil type and kind of crops. The crops like maize, pigeon pea, cotton, castor, soybean and sunflower respond very favorably to deep tillage. Patil *et al.* (2016) reported that conventional tillage conserved greater rainfall and improved soil physical properties, grain yield and water use efficiency (WUE) compared to reduced tillage in Vertisols of Karnataka (Table 1).

**Table 1.** Soil moisture, infiltration, sorghum yield and WUE influenced by tillage

| Tillage practices | Soil moisture (mm /60 cm depth) at the time of sowing | Infiltration (cm/hr) | Sorghum grain yield (kg/ha) | WUE (kg/ha/mm) |
|---|---|---|---|---|
| Conventional tillage | 278 | 9.0 | 433 | 2.21 |
| Reduced tillage | 210 | 8.2 | 388 | 2.0 |
| Less tillage | 195 | 7.4 | 343 | 1.87 |

### *Contour cultivation or cultivation across slope*

Contour farming is any effective and low-cost method of controlling erosion, conserving moisture and improving crop yields. The purpose of contour farming is to reduce runoff and soil erosion on mild slopes. This practice can also increase crop yield through the soil moisture retention in arid and semiarid regions. Generally, the common method of cultivation on sloping land is along the slope and it cause poor rainfall infiltration and accelerates soil erosion. Carrying out all the field operations including sowing of crops across the slope and along contour (contour cultivation) provides a series of miniature barriers to running rainwater and reduces runoff, soil loss and increases soil water and nutrient storage in soil profile. Contour cultivation is recommended for all types of soils, rainfall up to 1,000 mm and slope varying from 0.5 to 4%. It helps in reduction of runoff by impounding rain water in small depressions and reduces the development of rills. In practice it's often difficult to establish all crop rows on the true contour because of non-uniform slopes in most of the fields under Indian situations. In some situations, it's desirable to provide a small slope along the row (cultivation across the slope), to prevent runoff from a large storm breaking over the small ridges formed during the contour cultivation. The effectiveness of this practice varies with rainfall, soil type and topography. Maximum effectiveness of this practice is on medium slopes and on permeable soil.

**Table 2.** Benefits of contour farming

| Authors | Activity/soil | Benefit |
|---|---|---|
| Mourad and Joseph (2018) | Contour farming with vegetative strips in Alfisols | Reduction in sediment yield by 63% |
| Farahani *et al.* (2016) | Contour farming clay soils | 10% reduction in runoff and 49% reduction in soil loss |
| Seten *et al.* (2009) | Contour farming in clay soil | 72% reduction in runoff |
| Ramajaneyalu *et al.* (2020) | Contour farming with inter crop in rainfed alfisol | Higher soil moisture and maize equivalent yield |
| Krisnappa *et al.* (1994) | Contour farming inn Alfisols | 25% & 28% higher yield in finger millet and groundnut receptively |
| Ramamohan Rao *et al.* (2000) | Contour farming in Vertisol | 68% to 85% higher yield in winter sorghum across varies slopes |
| Sharda *et al.* (2006) | Contour farming and inter crop + green gram | Increased yield of crops by 15.4% to 26% and reduced soil loss by 17.6% to 25% |
| Kannan and Madhu (2013) | Ridges and furrows on contour | Increased infiltration, reduced soil loss by 30% and potato equivalent yield by 8% |

On long slopes, where bunding is done to decrease the slope length, the bunds can act as guidelines for contour cultivation. The benefit of contour farming in increasing crop yield and environmental benefit is given in Table 2.

### *Compartmental bunding*

Compartmental bunds convert the area square/rectangular compartment to impound rainwater. These are practices in medium and black soil area to store rainwater in the soil profile during mansoon for the use of *rabi* crop. Compartmental bunds provide greater opportunity time for rainwater to infiltrate into the soil and wet the soil profile completely for early sowing of winter crops thus giving greater crop yields. The size of the compartmental bunding varies with slope and slope of the field. Compartments of 6 m × 6 m up to 1% slope; 4.5 m × 4.5 m for 1–2% slope, and 3 m × 3 m for 2% slopes are recommended. In Vertisols at Bellary, compartmental bunding increased sorghum yields by 17% and water-use efficiency by 13% over flat bed. Increased soil moisture content and 36.7% higher chickpea yield due to compartmental bunding was also reported by Patil *et al.* (2016) in Vertisol of Bellary area.

### *Ridges and furrows*

Formation of fridges and furrows has been found most suitable for soil moisture conservation and to reduced runoff and soil loss, particularly in light soils. Open the furrows at 50 to 60 cm apart across the slope in medium to deep black soils, after completion of primary tillage, during the second fortnight of June to July out the field into ridges and furrows. Cultivation of crops under ridge- and furrow-system across the major land slope with a gradient of 0.2 to 0.4% in land having 1 to 3% slope will conserve more rainwater *in-situ*. This is suitable for widely spaced crops with 60 cm or more row spacing. At Bijapur, India, formation of ridges and furrows in Vertisols conserved more rainwater *in-situ* and resulted in 26% higher winter sorghum grain yields and 25% greater WUE over flat sowing (Patil and Sheelvantar, 2004).

### *Broad-bed furrow (BBF) system*

The ridges and BBF developed by the International Crops Research Institute for semi-arid tropics (ICRISAT, India) for increasing the productivity of semi-arid poorly drained Vertisols, provide more opportunity for infiltration of rainwater and at the same time prevent water logging of the crop growing on the bed. The BBF system consists of a relatively raised flat bed or ridge approximately 95 cm wide and shallow furrow about 55 cm wide and 15 cm deep across the slope on a grade of 0.2 to 0.6% for optimum performance.

The bed width also depends on the crops, soil type, and rainfall. The furrow act as drainage for removing excess water and broad bed stores rainwater. In block soil crops are sown in pre-formed beds made before the season and maintained year after year. This will save considerable cost as well as improve the soil health. This is suitable for narrow-spaced row crops. Even if a few rows are lost due to the furrow, the yields are make up owing to better *in-situ* rainwater conservation. There is no water stagnation in the bedding system. Hence this system acts both as disposal system during high intensity rains and as a conservation measure during low rainfall situations (Pathak *et al.,* 2009). Vekaria *et al.* (2015) found that adoption of broad bed (90 cm width) and furrow (45 cm) with 3 row was found superior for groundnut yield, net returns along with B:C ratio for maintaining higher soil moisture in root zone as well as for minimizing run off and soil loss in medium black soils under rainfed condition of North Saurashtra Agro-climatic Zone of Gujarat (Table 3).

**Table 3.** Effect of broad and furrow on groundnut yield and soil erosion

| Treatment | Runoff (%) | Soil loss (kg/ha) | Soil moisture (%) | Groundnut yield (kg/ha) | BC ratio |
|---|---|---|---|---|---|
| Flat bed 45 cm row spacing | 25.6 | 582 | 24.24 | 832 | 2.5 |
| Broad bed (90) cm and furrow (30 cm) with 3 crop row | 22.7 | 483 | 25.87 | 932 | 2.7 |

### *Conservation furrow system*

The conservation furrow is a simple and low cost *in-situ* soil- and rainwater-conservation practice adopted in Alfisols and associated soils with problems of crusting and sealing for rainfed areas (400–900 mm rainfall) with moderate slope varying from 1 to 4%. Due to crusting early runoff is quite common in these soils. Furrows at 3–5 m apart on contour or across slope are opened either during planting or during intercultural operation using country plough in this system. These furrows harvest the local runoff water and improve the soil moisture in the adjoining crop rows, particularly during the period of water stress. The practice has been found to increase the crop yields by 10–25%.

### *Zingg terracing*

Zingg terracing is adopted in low- to medium-rainfall areas in Vertisols with contour/ graded bunds. In Zing terrace nearly 30% of the area in the upstream side of the bund is levelled, so that in this levelled area assured crop yields are realized even during drought years. This is done by cutting 15 cm soil and putting it all near the bund to make flat land for 30% of the area in the upstream side of the bunds. Lower one-third portion of inter-bunded area is levelled to spread the runoff water in a large area. Usually water-intensive crops are cultivated in the levelled portion (receiving area), while dry crops are cultivated in the unlevelled (donor) area. In the levelled one-third portions, normal crop can be harvested even during severe drought year and it is possible to cultivate two crops during a normal year. This will increase both cropping intensity and crop yields in the region.

## Improve Soil Health and Soil Management

### *Mulching*

Mulching is the process of covering the soil between crops rows with the layer of crop residues, manures and other litter to reduce evaporation, increase infiltration, reduce runoff and control weeds. Mulches dissipate the kinetic energy of the rain drops, prevent soil erosion (splash erosion), facilitate infiltration, soil temperature regulation, and improve the water-holding capacity of the soil. As a result, supplemental water demand of the crops is reduced. Further through organic mulching and residue incorporation the biomass is returned to the soil which help in organic carbon build up in the soil. Kashif Akhtar *et al.* (2018) found that wheat straw mulch application in maize crop significantly influenced soil properties, soil organic carbon (SOC), available nitrogen, available phosphorus, total nitrogen and soil water content and maize grain yield (7%).

Vertical mulching involves opening trenches of 30 cm depth and 15 cm width across the slope at vertical intervals of 30 cm and stuffing sorghum stubbles vertically in these trenches, so that they protrude 10 cm above the ground. Vertical mulches of sorghum act as intake points and guide runoff water into subsoil layers thus, increases profile soil moisture and increased winter sorghum yields to a greater extent in a dry/drought year compared to wet/normal or above normal rainfall years. This technique in medium to deep stiff and clayey soils increased sorghum yield varying from 26 to 78%, respectively.

Live mulch is a cover crop, preferably leguminous crop inter planted or under sown with a main crop, to serve the purposes of a mulch, such as weed suppression and regulation of soil temperature and other environmental benefits. The concept of live mulching is based on mixed cropping whereby fast growing legume is established before or simultaneously along with widely spaced season grain crops and returned to the soil at an appropriate stage. In an experiment conducted at Dehradun, sunhemp (*Crotalaria juncea* L.), dhaincha (*Sesbania aculeata* Pers.) and cowpea (*Vigna unguiculata* L.) as a live mulch in maize-wheat cropping system, legume mulch accumulated 1.09–1.17 t/ha dry biomass and added 27.9–31 kg N/ha at 30 days after sowing and increased wheat yield by 13.3–14.0% (Sharma *et al.,* 2010a).

Also plastic film mulching plays an important role in agriculture owing to its ability to improve grain crop yields and water use efficiency (WUE) by maintaining soil moisture, suppressing weeds and increasing soil temperature. Plastic mulches directly affect the microclimate around the plant by modifying the radiation budget of the surface and decreasing the soil water loss. Subramaniyan *et*

**Table 4.** Effect of legume mulching soil properties and yield of maize and wheat

| Treatment | Bulk density (g/cc) | Infiltration rate (mm/hr) | Organic C (%) | Maize yield (t/ha) | Wheat yield (t/ha) |
|---|---|---|---|---|---|
| Control | 1.44 | 6.33 | 0.57 | 2.05 | 1.86 |
| Sunhemp | 1.41 | 7.36 | 0.64 | 2.23 | 2.04 |
| Leucaena | 1.36 | 7.67 | 0.66 | 2.19 | 2.06 |
| Sunhemp + leucaena | 1.36 | 8.34 | 0.69 | 2.36 | 2.38 |

*Source:* Sharma *et al*. (2010b)

*al.* (2018) found that transparent plastic mulch reduced moisture loss and increased black gram and groundnut yield under rainfed condition in Tamil Nadu, India. Even though plastic mulch role is well known, many environmentalists expressed concern about plastic pollution. To overcome negative environmental problems caused by persistent plastic waste from plastic mulch, biodegradable plastic mulches (BDM) have been developed as a promising alternative to plastic films, providing a sustainable and environmentally friendly solution for agricultural activities. Biodegradable plastic mulch use is on the rise as it provides many of the benefits of PE mulch with the advantage of being tilled in or composted at the end of the season, avoiding the disposal problems of plastic mulch.

## Conservation Agriculture

Conservation Agriculture (CA), comprising minimum mechanical soil disturbance and direct seeding, organic mulch cover from residues and cover crops, and crop species diversification through rotations and associations, is now practiced globally on about 125 M ha and worldwide. The technologies of CA provide opportunities to reduce the cost of production, save water and nutrients, increase yields, increase crop diversification, improve efficient use of resources, reduce runoff and soil loss and benefit the environment. In India, CA adoption is still in the initial phases. Over the past few years, adoption of zero tillage and CA has expanded to cover about 1.5 M ha. The major CA based technologies being adopted is zero-till (ZT) wheat in the rice-wheat (RW) system of the Indo-Gangetic plains (IGP). It is reported that CA which consists of permanent raised beds with a furrow and bed system, retention of 30% of standing crop residues and zero tillage on the top of the bed reduced runoff by 54%, soil loss by 79% besides increasing wheat yield under rainfed condition. Similarly, positive influence of CA on soil physical characters and soil organic build up were reported by several authors.

## Controlling Soil Erosion

### *Vegetative barrier*

Vegetative barrier, also known as live bunds are closely spaced plantations usually of a few rows of grasses or shrubs grown along the contour for erosion control in agricultural fields. These vegetative barriers not only help in resource conservation, but also provide much needed biomass to meet the needs of rural communities. In higher slopes it can be combined small bunds for improving its effectives. Vegetative barriers technology is highly beneficial for marginal and small farmers since it is cost effective and easier to establish. In India, different vegetative barriers have been identified for various agro-ecological regions and different soil (Sharda *et al.,* 2006). *Saccharum* spp. for alfisol of Orissa and Shivwaliks, *Cenchrus ciliaris* in dry vertisols, *Pennisetum hohenackeri* in dry Alfisols, *Pennisetum maximum* in the sub-humid lower wester Himalayas, *Panicum antidotale* and *Pennisetum polystachyon* for North Eastern Region were identified as effective or vegetative barrier. In an experiment conducted at Dehradun under rainfed condition, planting two rows of grass (*Cymbopogon martini*) at one meter vertical interval in 2% slope reduced runoff, soil loss and increased soil moisture availability and yields of maize-wheat cropping system (Gosh *et al.,* 2015). Dass *et al.* (2011) reported that Sambuta grass (*Saccharum spp*.)+trench cum bund treatment produced lesser runoff (8.1%) and soil loss (4.0 t/ha) followed by vetiver grass (*Vetiveria zizanioides*)+trench cum bund treatment (runoff 9.8%, soil loss 5.5 t/ha) compared to conventional practice in Orissa, India. In an experiments conducted in the field having 25% slope at Nilgiri hills revealed that planting geranium across the slope at 10 meter interval produced lesser soil loss higher potato equivalent

**Table 5.** Benefits of conservation agriculture

| Conservation agricultural practice | Author | Environmental benefit | Crop yield |
|---|---|---|---|
| No tillage with mulch | Ziyou Su *et al*. (2007) | Increased soil moisture content | 9% increase in rainfed wheat |
| No tillage with crop residue | Rafael *et al*. (2021) | Reduction in soil loss by 58% | 12% increase in maize yield |
| Zero till and residue retention | Govaert *et al.* (2009) | After 15 years of practicing, improved the dry aggregate size distribution | |
| Reduced tillage and residue incorporation | Somasundaram *et al.* (2019) | Conservation agriculture increased % of water stable aggregates, SOC | Higher soybean yield under CA |
| Zero tillage direct seeded rice followed by zero tillage direct seeded maize + residue retention | Singh *et al.* (2016) | Higher SOC content(27%), aggregates, root mass density | Higher maize yield |
| No-till raised bed with residue retention | Yadav *et al.* (2018) | Higher soil moisture content (17%) maize root mass density | Higher yield of maize |
| Reduced tillage and residue retention | Das *et al.* (2018) | Higher SOC (18%), soil microbial biomass carbon (SMBC) and dehydrogenase activity (DHA), and soil NPK | Higher pea (26%) and rapeseed (70%) yield |

yield. It was observed that within 3 years the original slope of 25.11% was reduced to 20.55% between the barriers resulting in a Land Improvement Index of 18.35 (Muralidharan *et al.,* 2008, Table 6).

## *Geo-textiles*

Geo-textiles are woven nets of fibre made from jute, coir or any other natural fibre used in soil conservation or any other soil related constrains in crop production. Several studies reported the benefits of geo-textiles in river bank protection and slope stabilization. The benefit of geo-textiles in field crop production and soil conservation also reported by few writers. Adhikari and Shankar (2018) reported that application of jute geo textiles increased rainfed groundnut yield by 64.2% and soil organic matter by 53% under rainfed condition in West Bengal, India. Field experiment conducted at Dehradun, on a 4% land slope in the Indian Himalayan Region (IHR) revealed that

**Table 6.** Change in slope (%) due to the vegetative barrier of Geranium on sloping land ($S_6$) and land improvement index

| Original slope | Average slope after | | LII after | |
|---|---|---|---|---|
| | 3 years | 4 years | 3 years | 4 years |
| 21.54 | 17.21 | 16.77 | 20.10 | 22.14 |
| 25.59 | 20.75 | 20.27 | 18.91 | 20.79 |
| 28.21 | 23.69 | 22.73 | 16.02 | 19.43 |
| (Mean) 25.11 | 20.55 | 19.92 | 18.35 | 20.79 |

*Source:* Muralidharan *et al.* (2008)

Agro Geo Textiles (AGT) prepared from giant-cane (*Arundo donax*) placed at 1 m vertical intervals recorded the highest ($p<0.05$) maize grain yield (2.8 t/ha), which was 36% higher than maize crops raised without AGT (conservation agriculture only). This treatment also reduced runoff (24%) and conserved soil losses (8.22 t/ha/yr). Productivities of succeeding pea (*Pisum sativum var. hortense*) and wheat (*Triticum aestivum* L. emend Fiori et Paol.) crops were enhanced by 122 and 36%, respectively (Singh *et al.,* 2019).

### *Contour bund and graded bunds*

Field bunding across the slope retains run-off in the cultivated field and facilitates its infiltration and reduce soil erosion. Contour bunds are laid across the major land slope along the contour lines in the areas having 1.5 to 6% land slope and having less than 600 mm annual rainfall. The minimum height of contour bund is 50 cm with a cross section of 1.61 $m^2$ having a vertical interval of 0.9 m and the horizontal interval between the bunds may vary from 50 to 70 m depending on the land slope. The graded bunds are constructed with a longitudinal grade of 0.2 to 0.4%, having a vertical interval of 0.75 m to divert the runoff from the fields. These bunds are more suitable for black soils with greater water logging in the periods of intense rainfall. With adequate vegetation the height of the bunds can be reduced to 50 cm. These bunds are recommended for the soils having less than 6% land slope. The graded bunds are connected to the water ways or water-harvesting structures with waste weirs.

However, contour bunding is not always successful. Prolonged water stagnation near the bunds usually damages crops and prohibits timely cultural operations. Loss of productive land and frequent breaking of bunds have also been reported from some areas, particularly those on clay soils. Under these circumstances, contour bunds with gated outlets were ensured adequate control of runoff and soil loss. Crops grown in the fields bunded by gated outlets yielded better than those grown in fields surrounded by conventional bunds.

### *Bench terracing*

Bench terracing is widely practiced soil conservation measures in hilly areas having high degree of slopes. It comprises of transforming original steep land into series of level strips supported by risers. It breaks the length of slopes and reduces the degree of slopes as well thereby conserving moisture and soil for better crop production (Sharda *et al.,* 2006). Though it is recommended for 16 to 33% slope, bench terracing is being practiced up to 50% slope in Nilgiri and Himalayan hills owing to socio economic condition. Bench terraces may be outward sloping, levelled or inward slopping based on crops grown, rainfall and soil. Levelled or table top bench terrace is recommended for medium rainfall region with highly permeable deep soil. Inward sloping bench terracing is more effective in high rainfall are for vegetable crops which require good drainage and susceptible to water stagnation. High rainfall region like Nilgiri hills inward bench terracing with 2.5% and 1% longitudinal gradient is recommended for sae disposal of water.

*Puertorican terraces:* Formation of bench terrace by conventional half cut and half fill method is expensive and if proper soil depth surveys are not conducted will result in exposure of sub-soil leading to reduced crop yields, in addition to the per cent area lost under risers which is equal to the per cent slope of land for 1.1 batter. To overcome these undesirable effects, studies on different types of terraces were conducted at ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Udhagamandalam to evolve a cheaper and effective method of developing bench terraces. It was found that Puertorican terrace with vegetative barriers using Guatemala grass (*Tripsacum laxum*) and Hybrid Napier reduced the cost of construction to one sixth and one third of the cost involved in the traditional method. Mixed vegetative barrier of two rows of pineapple and one row of Guatemala grass downstream at 1.0 and 1.5 m vertical interval also was successful in the formation of terraces at Gudalur. This technology is cheaper, easy to adopt, economical and eco-friendly. In the Western Ghats region, where majority of the cultivated area is highly sloping and the cultivation of annual crops and vegetable is underway in large areas, this technology is most appropriate in terms of both sustainable production and natural resource management. Vegetative barrier can be established with locally and economically suitable plants and additional income can be obtained from this also. Thus this technology can create revolution in the area of Natural Resource Management.

Puertorican terraces can be developed by first establishing a mechanical (earthen bunds or stone walls) or vegetative (a quick growing stiff stemmed vegetation that can stand the pressure of oncoming soil) barrier at the desired vertical along contour or graded line and then moving the soil against the barriers year after year at the time of preparation of cultivation, without incurring any extra expenditure. Studies have indicated that regular bench terraces can be developed by this method over a period of 3 to 5 years (steeper the slope, shorter is the duration). The recommended soil moisture measures based on rainfall is given in Table 7.

**Table 7.** Recommended soil and moisture-conservation measures for different rainfall zones in India

| Seasonal rainfall (mm) | | | |
|---|---|---|---|
| **<500** | **500–750** | **750–1000** | **>1000** |
| Contour cultivation | Contour cultivation | BBF (vertisols) | BBF (vertisols) |
| Conservation/ dead furrows | Conservation furrows | Conservation furrows | Field bunds |
| Ridges and furrows | Ridging | Sowing across slope | Vegetative barriers |
| Sowing across slope | Sowing across slope | Tillage | Graded bunds |
| Mulching | Vegetative barriers | Vegetative barriers | Vegetative bunds |
| Scoops | Scoops | Small basins | Chos |
| Compartmental bunding | Tied ridges | Vegetative bunds | Level terrace |
| Graded border strips | Mulching | Field bunds | |
| Tied ridges | Zing terrace | Graded bunds | |
| Off-season tillage | Off-season tillage | Nadi | |
| Inter-row water harvesting system | BBF | Zingg terrace | |
| Small basins | Inter-row water harvesting system | | |
| Contour bunds | Small basins | | |
| Field bunds | Modified contour bunds | | |
| Khadin | Field bunds | | |
| Graded bunds | Graded bunds | | |

## *Water harvesting*

Rainwater management is one of the critical components in rainfed farming and the successful crop production depends on *in-situ* moisture conservation, surplus runoff water collection, storage and recycling (Rao *et al.,* 2017). Further, the importance of rainwater harvesting for agriculture is now more urgent with increased climatic variability and higher frequency of extreme weather events (Rao *et al.,* 2009; IPCC, 2014). Extremes, untimely and high intensity rainfall experienced in recent years are likely to continue and cause surplus runoff. There is a scope for utilize this surplus runoff water through storage structure for supplementary irrigation in semi arid region and increase the cropping intensity in high rainfall region. Over the recent decades, interventions around rainwater harvesting have been an important component of rural and agricultural development programmes in India and many water harvesting structures were created with the public funding from schemes like Mahatma Gandhi National Rural Employment Guarantee Scheme (MNREGS), Integrated Watershed Management Programme (IWMP), National Agricultural Development Programme (RKVY) and National Horticultural Mission (NHM) and Pradhan Mantri Krishi Sinchai Yojana (PMKSY). High rainfall variability (AICRPDA, 1991-2011) in the selected seven study districts further makes an important case for rainwater harvesting for agriculture. Research institutions have worked on designing efficient rainwater harvesting structures for different rainfall regions and soil types, effective storage of harvested water and methods for its efficient use in the Indian context (Kumar *et al.,* 2011). He also reported that use of farm ponds in Maharashtra resulted in a significant increase in farm productivity (12–72%), cropping intensity and consequently farm income. In the Chittoor district of Andhra Pradesh, farm pond water was profitably used for supplemental irrigation to mango plantations, vegetables or other crops.

Although rainfall in high rainfall regions is sufficient to meet the water demand of crops, its spatial and temporal distribution makes rainfed farming a risky proposition. Water harvesting can reduce the risk substantially by facilitating early planting by taking maximum advantage of the rainfall, thereby insuring the crop against rainfall aberrations. The proper design of a water harvesting system in a high rainfall region should take into account the spatial and temporal behavior of rainfall, water requirement of the crops, in addition to catchment characteristics. Srivastava *et al.* (2001) reported that for a rice-based cropping system in eastern India, a catchment/command ratio of 3.0 and tank size of 1750 $m^3$/ha command area is required, which facilitates desirable moisture regime for rice and two irrigations to succeeding crop. Kannan *et al.* (2017) found that in high rainfall area of the Nilgiri hills, harvesting runoff water in 800 cu. m size was sufficient to take up one additional summer crop and supplementary to kharif and rabi crop. Through this intervention cropping intensity could be increased from 200 to 300% besides increasing farm income to the tune of 111% (Table 8).

In the rainfed rice production system of Eastern India, in situ moisture conservation of rainwater through optimum weir height and conservation o0f run-off water through runoff collection refuge (5–8% of area of individual field) at the end of the field and supplementary irrigation increased the

**Table 8.** Effect of farm pond on productivity and income in the farmer's field in hilly area

| Components | Names | Area(Acre)/ number | Production (Q) | Gross income (Rs) | Net income (Rs) |
|---|---|---|---|---|---|
| **Before intervention** | | | | | |
| Field crop 1 | Potato | 1.5 | 126.6 | 189900 | 54900 |
| Field crop 2 | Carrot | 1.5 | 177.0 | 354000 | 174000 |
| Total | 543900 | 228900 | | | |
| **After intervention** | | | | | |
| Field crop 1 | Potato | 1.5 | 145.8 | 217500 | 82500 |
| Field crop 2 | Carrot | 1.5 | 201.0 | 402000 | 222000 |
| Field crop 3 | French bean | 1.5 | 78.0 | 195000 | 174000 |
| Fish | Mirror carp | 450 $m^2$ | 0.2 | 8000 | 5000 |
| Total | | | | 822500 | 483500 |

rainfed rice productivity from 1.8 t/ha to 4.53 t/ha and cropping intensity to 176% (Mishra *et al.*, 2003). At watershed level, Srivastava *et al.* (2009) and Kannan *et al.* (2006) evaluated the tank cum open dug well system suitable for plateau region of eastern India has been developed for providing reliable irrigation to croplands. The system comprises of a series of tanks with open dug wells in the recharge zone of the tank that re harvest back the seepage water. Thus, the rainwater remaining in the tank as well as partial seeped water is used for providing round the year full irrigation. This system was evaluated in field in Keonjhar district of Orissa of eastern India with six tanks and five wells in two drainage lines. The total command area of the system of six tanks and five wells in both drainage lines is 23 ha and the total irrigation potential is 44.5 ha. The system increased the rice yields from 1.92 t/ha to a range of 2.25 to 3.8 t/ha depending upon the package of practices or the amount of inputs.

## Conclusion

Conservation of precious natural resources is a vital important to meet the needs of the growing population. Some of these technological interventions are too costly where farmers are not in a position to adopt it due to socio-economic constraints without the support from public and private investments. However, farmers should be encourage to practice low cost technological interventions which can be easily adopted without much cost on it and sometime non-monetary inputs, soil and water management practices also yield better result interims of productivity enhancement. Convergence approach of many programmes and schemes are to be practiced at the field implementation level to achieve the cumulative benefits of resource conservation technologies.

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# Integrated Farming Systems for Smart Agriculture

**A.S. Panwar, K.J. Raghavendra*, Raghuveer Singh, N. Ravisankar, Meraj Alam Ansari, M. Shamim and A.K. Prusty**

*ICAR-Indian Institute of Farming Systems Research, Modipuram-250110, Uttar Pradesh*

**Email: raghavendra.kj@icar.gov.in*

**ABSTRACT**

Over the time agriculture evolved with new technologies to augment the production and achieve the food security. In today's world for sustaining yield and improve income of the farmers is at high stake. IFS is becoming familiar among the farmers for integrated use and management of land, water and human resources to maximize income and employment. Production under IFS can be accelerated by adoption of smart technologies to improve the rural life. Smart farming practices with intervention of IT has advanced to much higher level of problem solving with minimal interface with cultivation activities. Smart technologies like zero tillage, rain water harvesting, leaf colour charts, laser levellers will enhance the productivity and profitability. Precision farming with adoption of smart irrigation and fertilizer application, conservation practices for soil health, ICTs will enhance the resource use efficiently thereby farmers livelihood.

Indian agriculture faces serious challenge in attaining sustainability and profitability of farming due to decline in land holding. The average size of operational holding in India is decreased from 1.41 ha in 1995-96 to mere 1.08 ha in 2015-16. The farming community characterised with illiterate, financially handicapped, their holdings are small and scattered, resource poor and frequently exposed to diverse risk and uncertain conditions. Under this prevailing situation, focus should be on adopting advance technologies which integrate agriculture and subsidiary enterprises to make farming more profitable, employment generation and attain sustainability is much necessary (Gangwar and Prasad, 2005). At ICAR and State Agricultural Universities level, lot of efforts have been made aiming at increasing the productivity of different components of farming system like crop, dairy, livestock, poultry, piggery, goat keeping, duckery, apiculture, sericulture, horticulture, mushroom cultivation etc. individually but lacking in their integration by following farming system approach (Gill *et al*., 2009). As integrated farming systems are less risky, they benefit from synergisms among enterprises, diversity in produce, and environmental soundness (Ravisankar *et al*., 2007). Over the time improvement has been made in farming systems research through development of suitable models for different Agro climatic zones through AICRP-IFS scheme under different scenarios (Panwar *et al*., 2018).

Over the time through technological progress opens several opportunities for the different socioeconomic sectors, including the farming sector, in a perspective of smart agriculture, but not without several challenges (Martinho and Guine, 2021). Smart farming is use of modern technologies to increase quality and quantity of agriculture production. The studies also highlight the relevance of the smart agriculture concept and practices to increase the sustainability in the agriculture. Smart agriculture practices are envisaged as the most suitable adaptation strategies that will allow achieving food and, while at the same time being able to mitigate climatic changes. Smart agriculture includes a number of technological, policy, and institutional interventions (Aggarwal *et al*., 2004) revolving around seed, water, energy, and nutrients and some risk-averting and risk-insuring instruments that increase the resilience and stability of agriculture (Taneja *et al.*, 2019) and thus help farmers adapt to and reduce the risk of climate change. The smart technologies (Table 1) with broad characteristics are classified based on the principle of triple wins, as discussed above. These smart technologies under IFS models will enhance sustainable production and income augmentation for farmers (Ravisankar *et al.,* 2020). The water scarcity in IFS model can be managed by adopting technologies like construction of rainwater harvesting structures especially in arid and semi-arid regions, land levelling can be done in sloppy areas for reducing water runoff and proper irrigation (Gupta *et al.*, 2012). Furrow irrigated raised bed is another technology to use water efficiently for irrigation purpose. The energy smart technologies like direct seeded rice in paddy cultivation reduces cost of cultivation and tractor power by sowing dry seeds into field. Zero/minimum tillage a prominent technology to reduce carbon emission, minimal soil disturb, residue incorporation will augment the soil carbon and improve soil health.

**Table 1.** Smart technology options for Integrated farming systems (*Source:* Taneja *et al.*, 2019)

| Technologies | Definitions |
|---|---|
| **1. Water smart technologies** | **Interventions that reduce water requirements to produce the same or a higher level of yield** |
| • Rainwater management | In situ rainwater storage in fields with 20–25 cm bunds |
| • Laser land levelling | Levelling of land with a laser leveller |
| • Furrow-irrigated raised bed | Growing crops on ridges or beds. Irrigation is applied through furrows separating the beds |
| **2. Energy-smart technologies** | **Technologies that help reduce energy consumption without affecting yield levels** |
| • Direct-seeded rice | Dry seeds are sown either by broadcasting or drilling in line |
| • Zero tillage/ minimum tillage | The crop is seeded through a seeder in an untilled field, and the crop residue is incorporated into the soil. |
| **3. Nutrient-smart technologies** | **Technologies that save/supplement/avoid chemical fertilizer use for crops and enrich carbon in the soil** |
| • Green manure | In-situ cultivation of green manure crops/ legumes in a cropping system. This practice improves nitrogen and soil health/quality. |
| • Integrated nutrient management (INM) | Integrated use of organic and chemical fertilizers to optimally use NPK (nitrogen, phosphorus, and potassium) requirements without affecting productivity and improve soil health |
| • Leaf colour chart | Standardized colour charts are used to identify nutrient deficiency to estimate fertilizer doses in different field locations |
| **4. Weather-smart instruments** | **Interventions that provide services related to financial security and weather advisories to farmers** |
| • Crop insurance | Crop-specific insurance to compensate income loss due vagaries of weather. |
| • Weather advisories | Information and communication technology–based forecasting about the weather. |

Efficient utilization of fertilizer can be done by cultivation of green manuring and incorporation into field or legume crops cultivation, use of INM practices by integrating organic and inorganic fertilizers for balance use and identification of nutrient deficiency using leaf colour chart for optimum use of nutrients in the farm. There is always some risk and uncertainty in farming, to an extent it can be reduces by adopting integrated farming systems as it avoids risk of price and weather to extent but not fully, so through opting for crop insurance weather risk can be transferred to institutions. Farmers should adopt to different ICTs for efficient utilization of extension services for adoption of improved technologies available.

*Recycling of wastes:* The agricultural wastes and inputs like cow dung/litter in IFS is to recycle to reduce the cost on manures and fertilizers and also provide eco-friendly production environment. Through AICRP-IFS in which various location-specific modules including plantation crops, orchard, dairy, goat, sheep, poultry, fish, pig, apiary, mushroom, biogas, and boundary plantations have been integrated with an aim to meet the household demand of 4Fs (food, fodder, feed and fuel), besides recycling of wastes to meet the nutrient requirement of different components. At present across the major systems, farmers are applying 33.3, 38.8, 57.1 and 93% less application of N, P, K and micronutrients (MN) compared to the recommended doses (Bhaskar *et al.,* 2021; Paramesh *et al.*, 2021) this can be supplied by recycling of farm wastes available. Study by Panwar *et al.* (2021) in western and eastern Himalayan region, the results obtained from these IFS models revealed that at Palampur (WHR) 80.2 kg N, 40.1 kg $P_2O_5$ and 80.2 kg $K_2O$ could be recycled while in the IFS model of Pantnagar, 129 kg N, 65 kg $P_2O_5$ and 134 kg $K_2O$ was recycled. The study on nutrient recycling in these IFS models revealed that 359.4 kg N, 76 kg $P_2O_5$ and 217.7 kg $K_2O$ could be recycled in IFS model at Jorhat while 140 kg N, 31 kg $P_2O_5$ and 85.5 kg $K_2O$ was recycled at Umiam (Fig. 1).

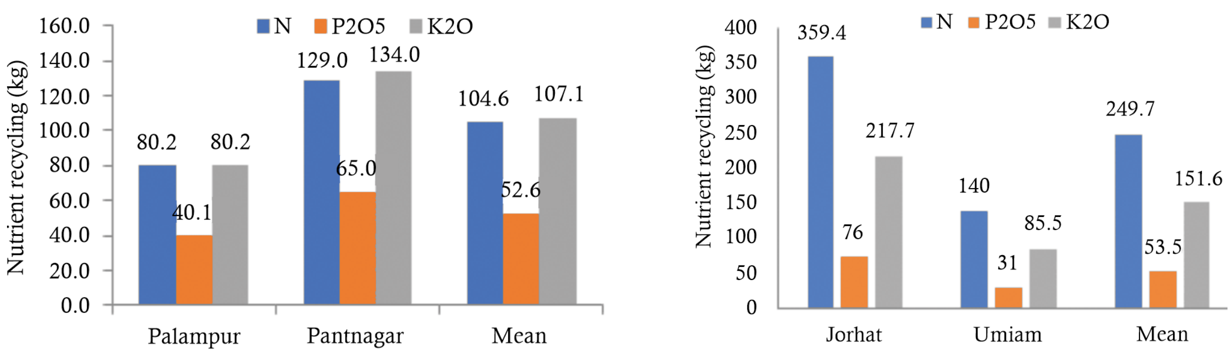


**Fig. 1.** Nutrient recycling in IFS of Western Himalayan Region and Eastern Himalayan Region models
*Source:* Panwar *et al.* (2021)

Study by Kumar *et al.* (2017) shows that the recycling (Table 2) of nutrients through application of farm generated vermicompost, cow dung and sheep litter has saved the expenditure to the tune of Rs. 12,634. In the model a total of 249 kg of N, 78 kg of P and 135 kg of K was recycled and utilized, this makes reduction of cost of cultivation by reduced external fertilizer purchase and also adds organic matter to soil.

*New technologies and approaches*: Smart agriculture gained momentum with the time, by intervention of IT in the field of agriculture. The Internet of Things (IoT) had great impact on the farms and are forms to improve the productivity in the use of several agricultural resources, viz, water, through approaches of smart irrigation and precision agriculture. The smart irrigation systems are important to collect and work environmental data. The IoT allows to implement automated operations with reduced supervision in the whole food systems and agricultural production, including in greenhouse agriculture and in diverse farming systems. The potable water will be one of the scarcest resources,

**Table 2**. Total amount of nutrient added through recycling and its market value (*Source:* Kumara *et al*. 2017)

| Recyclable farm waste | Quantity (kg) | Nutrient content (%) and total recyclable nutrients (kg) | | | Quantity of fertilizers (kg) | In terms of rupees (Rs.) |
|---|---|---|---|---|---|---|
| | | (N (kg) | P (kg) | K (kg) | | |
| Vermicompost | 3217 | 32.17 | 11.91 | 17.05 | 54.5 (Urea) | 3784 |
| Cow dung | 7754 | 85.29 | 33.34 | 36.44 | 489.2 (SSP) | 4256 |
| Sheep litter | 4462 | 131.63 | 33.02 | 81.65 | 229.7 (MOP) | 4594 |
| Total | 15433 | 249.09 | 78.27 | 135.14 | - | 12634 |

IoT may contribute significantly for a more balanced use of it, as well as in the soil health assessment and fertilization management. soil testing approach prior to crop planting, in-season nutrient management based on sensors, and split application of N fertilizers could be opted for improving NUE. Use of local or remote N sensors could be helpful in sophisticated management practices to assess plant needs for supplemental N. Different sensors in the agriculture sector play a significant role in IoT technologies (Suma, 2021). Connecting multiple interconnected devices, such as several sensors, drivers and smart objects, to mobile devices through the use of the Internet. Cultivation including all activities such as irrigation, plant growth, identification of disease, and production management in the smart agriculture sector. In order to achieve the target progressively, many new innovations can be combined with traditional farming. Instruments like integrated soil nutrient and moisture analyser to calculate the level of various soil nutrients and water moisture level in soils, so that whichever components is deficient, will be supplied in time and also irrigation at right moment (Vadalia *et al*., 2017). Precision farming is increasingly becoming an established farming practice that optimizes crop inputs by striving for increased efficiencies of those inputs thus increasing profitability while at the same time reducing the environmental footprint of those improved practices (Hopmans *et al*., 2021). It offers the potential to automate and simplify the collection and analysis of information. It allows management decisions to be made and quickly implemented on small areas within larger fields.

*Multipurpose solar power:* Energy is a key resource for the overall development of an economy. India has been endowed with abundant renewable solar energy resource and in this large country where the rate of electrification has not kept pace with the expanding population, urbanization and industrialisation which have resulted huge gap between demand and supply of electricity. People not served by the power grid have to rely on fossil fuels like kerosene and diesel to meet their energy needs. This may also lead to incur more and more recurring expenditure on irrigation by the small and marginal farmers. Further most parts of the country experiences 250–300 sunny days in a year, which makes solar energy a viable option in these areas. Decentralised renewable energy systems, which rely on locally available resources, could be the solution to the rural energy problem, particularly in remote areas where power grid is not a viable proposition. The high cost of electricity, fast depleting fossil fuels have led to a surge of interest for utilization of solar energy among the institutions. It is also becoming increasingly difficult to meet the exponential growth in demand of Agricultural productivity which is closely associated to direct and indirect energy inputs. Under non-conventional energy source, power generation can be made through Biomass, windmill, small Hydro Electric, Solar Photovoltaic and Solar Thermal systems. Among solar technologies useful in irrigation sector are pumping and water lifting (Uddin *et al*., 2020). Solar power is available at the point of use, making the farmer independent of fuel supplies or electrical transmission lines. Under the scheme PM-KUSUM, Ministry of new and renewable energy, also promoting implementation of solar operated pumps among farmers with subsidized implementation and also the training for skills necessary to operate the technology. In IFS along with water lifting the solar power can be utilised for the other activities like operating small processing units like dryers, shredders, husking of produce with respect to spices, pulses, cereals and other commodities. Through NABARD the financing facilities also provided for adoption of solar operated pumps and electric grids with specified models of capacity.

*Information communication technologies (ICTs)*: Today it becomes a vital communication tool cutting across gender, place and also the different classes of society to improve productivity. Now that huge investment on IT infrastructure development in rural India by renowned NGOs and funding organizations have neutralized the effect of digital divide and India is in a state to access information virtually. As today's farming is becoming highly knowledge intensive, commercialized, competitive and globalised against traditional approach, the call for the precise approach to draw together collaboration between the researchers, farmers, extension workers, agribusiness traders and civil societies will lead to collective development (Prakash *et al.*, 2017). The IFS farmers need to adopt the ICT based services such as market access, technologies information, price determination, and others to achieve the productivity.

## Conclusion

Farming in this competing world has to be updated itself for technological adoption. Practices of adopting smart technologies as we discussed in this paper have huge potential to improve the income and eco-friendly production. Precision farming becoming much popular in adopting sensors and land levellers along with irrigation systems for more efficient utilization of available scares resources. Solar powered pumps help in cost cutting and year-round power availability thus increasing productivity and profitability of farmers. ICTs have tremendous work done in dissemination of information related to market access, new technologies and innovations. Thus, IFS farmers should adopt of these innovative smart technologies for upscaling among community sustainable livelihood.

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# Salt Affected Soils and Their Management in Indian Context

**P.C. Sharma* and Ashim Datta**

*ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana*
*Email: pcsharma.knl@gmail.com*

**ABSTRACT**

In 21st century land degradation due to salinity and sodicity is an important constrain for sustainable crop production. To increase awareness and tackle ecosystem degradation, UN has declared 2021-2023 is the "Decade on Ecosystem Restoration" which aims to prevent, halt and reverse the degradation of ecosystems on every continent. This can help to end poverty, combat climate change and prevent a mass extinction. In India, considerable area is affected by salinity and sodicity thereby impaired crop productivity. Therefore, management of salt affected soils is a priority. Salt-affected soils can be reclaimed by improving drainage, leaching, reducing evaporation, applying chemical treatments, and a combination of these methods. In this article, an attempt is made to collate recent technologies as developed by CSSRI for management of salt affected soils. The amelioration of salt affected soil has the potential to mitigate the accelerated greenhouse effect by increasing soil carbon through biomass production. Therefore, salt affected soils should be considered as a useful resource of economic value rather than an environmental burden. These soils can be reclaimed through proper management practices and used for growing crops to feed the burgeoning population of the country under the present scenario of changing climate.

## Introduction

Land, a non-renewable resource is the base for all primary production systems. Now-a-days for good quality land and water resources, domestic and industrial sectors are competing with agriculture. There is an enormous pressure on limited land resources due to the growing human population and increased food demand. Multiple resource degradation problems are emerged due to the over exploitation of natural resources for food and nutritional security of the burgeoning population thereby threatening the sustained productivity of the limited land resources. In India, salt affected lands cover around 6.73 M ha of agricultural land with varying degrees of salinity and are considered a serious concern to sustainable food production of the country. By 2050 this is likely to increase manifold with the projected increase in salt-affected soils to 16.2 million ha (CSSRI Vision, 2050). Therefore, after proper reclamation measures, these salt affected lands should be utilized and brought under productive cultivation in the years to come to meet the food requirement of the increasing population of the country.

Plant growth is not affected when salts concentration is below a certain critical level. On the contrary, when the salt concentration rises to some high value beyond the critical value, plant growth is adversely affected; this in turn decreases the production of agricultural crops. Mostly such type of soils are found in the arid and semi-arid regions, where the annual rainfall is not sufficient to leach salts to deeper soil layers coupled with high evaporation leading to accumulation of salts in root zone. These soils also occur extensively in sub-humid and humid climates, particularly in the coastal regions where the ingress of sea water through estuaries and rivers and through groundwater causes large-scale salinization. Accumulated salts contain the cations $Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$, and the anions such as $Cl^-$, $SO_4^{2-}$, $HCO_3^-$ and $CO_3^{2-}$. These ions may be formed from mineral weathering and accumulated in low rainfall areas or carried by runoff water and accumulated in depressions.

## Extent of Salt Affected Soils

India is by far no different from others having 6.73 million hectare of salt affected lands (Mandal *et al.,* 2010) (Table 1).

Salt affected soils based on their origin, nature, characteristics and plant growth relationships classified into three groups i) saline soils ii) sodic/alkali soils, iii) saline-alkali soils.

## Saline Soil

Soil that contains sufficient soluble salts to impair its productivity is known as saline soils, also called as Solonchak. These salts are mainly of chlorides and sulphates of sodium, calcium and magnesium. In arid climatic regions, saline soils may have excessive amount of boron, fluoride as well as nitrates. Sometimes appreciable amount of sparingly soluble gypsum is also observed in some patches. As per the US Salinity Laboratory Staff (1954), the distinguishing features of saline soils from agricultural stand point, is that they contain sufficient neutral soluble salts to adversely affect the growth of most crop plants. They must have an electrical conductivity of the saturated soil extract ($EC_e$) more than 4 dS $m^{-1}$ at $25^0C$, pHs less than 8.5, and exchangeable sodium percentage (ESP) less than 15. But as per Gupta and Abrol (1990) saline soils have pHs less than 8.2, $EC_e$ more than 4 dS $m^{-1}$ and the preponderance of chlorides and sulphates of Na, Ca and Mg. Soil salinity classes mainly based on their conductivity of saturation extract, are given in Table 2.

The process of formation of saline soils is known as salinization. Salinization is a natural process which occurs from weathering of minerals or from deposits of fossil salts. Low rainfall in arid and semi-arid climates is unable to leach down the soluble weathered products resulting in the deposition of these salts at the soil surface causing salinity hazards. Some of the human activities accelerating the salinization process are excessive use of basic fertilizers such as sodium nitrate, basic slag etc.,

**Table 1.** The state-wise occurrence of salt affected soils in India (Mandal *et al*., 2010)

| State | Saline (ha) | Sodic/ Alkali (ha) | Total |
|---|---|---|---|
| Andhra Pradesh | 77598 | 196609 | 274207 |
| Andaman & Nicobar | 77000 | 0 | 77000 |
| Bihar | 47301 | 105852 | 153153 |
| Gujarat | 1680570 | 541430 | 2222000 |
| Haryana | 49157 | 183399 | 232556 |
| Karnataka | 1893 | 148136 | 150029 |
| Kerala | 20000 | 0 | 20000 |
| Madhya Pradesh | 0 | 139720 | 139720 |
| Maharashtra | 184089 | 422670 | 606759 |
| Odisha | 147138 | 0 | 147138 |
| Punjab | 0 | 151717 | 151717 |
| Rajasthan | 195571 | 179371 | 374942 |
| Tamil Nadu | 13231 | 354784 | 368015 |
| Uttar Pradesh | 21989 | 1346971 | 1368960 |
| West Bengal | 441272 | 0 | 441272 |
| Total | 2956809 | 3770659 | 6727468 |

**Table 2.** Soil salinity classes based on electrical conductivity of the saturated extract and their effects on crop plants (Jehangir *et al*., 2013)

| Soil salinity class | Conductivity of saturated extract ($dS\ m^{-1}$) | Effect on crop plants |
|---|---|---|
| Non saline | 0-2 | Salinity effects negligible |
| Slightly saline | 2-4 | Yield of sensitive crops may be restricted |
| Moderately saline | 4-8 | Yield of many crops are restricted |
| Strongly saline | 8-16 | Only tolerant crops yield satisfactory |
| Very strongly saline | >16 | Only a few very tolerant crops yield satisfactorily |

removing native vegetation, growing shallow-rooted annuals and excessive irrigation increases leakage of salts to the groundwater system. Use of saline ground water for irrigation and rise of water table brings salt to the root zone and on the soil surface and have accelerated the process of salt mobilisation and accumulation. Salinity is often classified into several different categories like dryland salinity, irrigation salinity, urban salinity and industrial salinity based on the broad cause.

## Sodic Soils

Sodic soil contains sufficient exchangeable sodium (Na) to adversely affect crop production and soil structure under most conditions of soil and plant type. Carbonates and bicarbonates of sodium are the dominant salts and the concentration of neutral salts is very low. Sparingly soluble gypsum is nearly absent. The pH of the soils usually varies in between 8.5-10.0, $EC_e$ is less than 4 $dS\ m^{-1}$, exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) more than 15 and 13, respectively. Earlier these soils are popularly known as black alkali soils. Under high pH, organic matter get dissolved and deposited on the soil surface forming a thin film over the soil particles. This happens when water evaporates through capillary action. These soils are mainly distributed in the arid and semi-arid regions of Punjab, Haryana, Uttar Pradesh, Bihar and Rajasthan.

## Saline-sodic Soil

Saline-sodic soil is defined as a soil having a conductivity of the saturation extract greater than 4 $dS\ m^{-1}$ and an exchangeable sodium percentage (ESP) greater than 15. The pH is variable and usually above 8.5 depending on the relative amounts of exchangeable sodium and soluble salts. These soils form as a result of the combined processes of salinization and alkalization. If the excess soluble salts of these soils are leached downward, the properties of these soils may change markedly and become similar to those of sodic soil.

## Sodic Soil Reclamation

For reclamation of sodic soils, various chemical substances such as gypsum, sulphuric acid or acid forming substances like pyrite and lesser soluble limestone etc. have been tried. But because of abundance, cost effectiveness and easier application method, gypsum ($CaSO_4.2H_2O$) has proved to be the best amendment so far for sodic soil reclamation. Gypsum requirement (GR) is worked out to calculate the amount of gypsum required to be applied to reclaim a sodic soil often neglecting the role of native calcite in the exchange process. Various soil factors such as $CO_2$ enrichment in soil water, alkalinity of irrigation water and Ca content enhance dissolution of native calcite in spite of its insoluble character (Suarez, 2001). Moreover, in saline-sodic soils of the Indo-Gangetic Plains presence of higher amounts of sodium carbonate produces insoluble $CaCO_3$ by reacting with soluble carbonates with subsequent decrease in Ca ion concentration of gypsum solution and this ultimately lead to overestimation of GR (Abrol *et al*., 1975). Costs of reclamation may increase due to excess use of gypsum amendment and also results leaching of salts to the groundwater. At any given equilibrium between Na and Ca, practically complete exchange reactions hardly occur, thereby leaching of Ca takes place through movements from root zone.

Therefore, for precise GR estimation quantitative models with integration of all such factors need to be developed. In areas with high RSC groundwater of north-western India, the use of underground pipes for irrigation purposes is increased. This necessitates the need for development of alternative technologies for mixing amendments with irrigation water for their sustainable (ICAR-CSSRI, 2017). In addition to these constraints, continuously declining availability and quality of mined gypsum are the most important concerns to its use as an amendment (IBM, 2015). Purity of currently available gypsum is ~40% as per the laboratory analysis (ICAR-CSSRI, 2018) against the prescribed limit of >70%. Therefore, alternative amendments need to be explored to harness their reclamation potential for sodic soil reclamation.

## Synthetic Alternatives of Mined Gypsum

The industrial by-products having potential as sodic soil ameliorants and conditioners are termed as synthetic gypsum. Such products are flue gas desulfurization gypsum (FGDG), phospho-gypsum (PG), phosphoric acid, titano-gypsum (TG), fluoro-gypsum (FG) and citro-gyspum (CG), the by-products of coal-fired power plants, phosphoric acid, titanium dioxide, hydrofluoric acid and citric acid manufacturing industries, respectively. Studies on assessment of FGDG and PG on their sodic soil ameliorative effects have been initiated (Zhao *et al*., 2018). Gharaibeh *et al*. (2010) reported the cost effectiveness and efficiency of phosphoric acid over PG in sodic soil reclamation although more studies are required to establish phosphoric acid as a viable amendment under field conditions. The potential of titano-gypsum (Meriño-Gergichevich *et al*., 2010) and citro-gypsum (Kos *et al*., 2007) as probable amendments for alleviating sodicity stress need to be evaluated. Therefore, for developing suitable package of site specific agro-practices, long-term systematic studies are needed to harness the potential of these synthetic alternatives of gypsum in sodic soil reclamation without any accumulation of heavy metals.

## Bio-augmented Materials

Two or more organic substances can be combined and might manifest better performance than their sole use after soil application and also can help in reducing the reliance on relatively costly chemical ameliorants. Total soil organic carbon and soil enzyme activities were improved after application of a bio-augmented formulation, consisting of plant growth promoting fungi inoculated vermicompost, press mud and *Azadirachta indica* seed cake in a silty loam sodic soil with pH of 9.2 and ESP of 60% (Srivastava *et al*., 2016). However, reclamation efficiency of combined use of bio-augmented substances and chemical amendments on improvement of sodic soils need to be studied.

Recently Drake *et al*. (2015) had showed the potential of 'biochar' in reclamation of salt-affected soils in addition to its major use as a long-term sink for atmospheric $CO_2$ sequestration. Conjunctive addition of FGDG and biochar improved sodic soil conditions (Schultz *et al*., 2017; Alcívar *et al*., 2018) and therefore, warrants systematic studies to unravel the individual and synergistic effects of biochar (B), humic substances (HS) and chemical amendments for achieving their conjunctive use potential in sodic soil reclamation and plant growth.

## Superabsorbent Polymers and Nano-materials

Reports are available on the efficiency of superabsorbent polymers such as hydrogel on amelioration of sodic soil and irrigation water as well as modulation of plant metabolism (Shokuohifar *et al.*, 2016; Tadayonnejad *et al.*, 2017). It has been found that $Na^+$ concentration in soil solution also increased upon hydrogel application, therefore efforts should be made to develop compounds that would not release salt ions into soil solution. More recently, nano-materials or engineered nanoparticles (ENPs) have also shown promise in improving the infiltration rate and soil aggregate stability as well as efficient in decreasing the surface run-off and structural instability of sodic soils. Combined application of sulfur coated (15 Mg $ha^{-1}$) municipal solid waste compost (MSWC) and nano-iron oxide powder (20 mg $kg^{-1}$) lowered pH and SAR of a saline-sodic soil (Ghodsi *et al.*, 2015). Soil pH, EC, bulk density and $CaCO_3$ content were decreased upon application of polymeric aluminum ferric sulfate (PAFS) and the saturated hydraulic conductivity was increased in a highly dispersed saline-sodic soil (Luo *et al.*, 2015). Production and use of ENPs have not gained commercial scale in spite of encouraging observations, for commercialization and wider adoption by the farmers more systematic information are needed.

## Nano Clay and Nano Gypsum

Nano clays can serve as an excellent option to tackle with high RSC poor quality water which can be used for irrigation purpose. Systematic research in this direction is required.

Nano-gypsum with higher surface area can be an excellent material which can be used to reclaim alkali soils. As compared to mined gypsum, the requirement would be lower with higher purity. Kumar and Thiyageshwari (2018) reported the efficiency of nano-gypsum (100% GR) in reducing the soil pH and ESP. More studies are required in this aspect.

## Marine Gypsum

Assessment and use of marine gypsum (MG) for reclamation of sodic soil has gained interest among the researchers due to a rising concern on availability and purity of mined gypsum (IBM, 2015). The ionic strength of marine gypsum in aqueous solution might increase due to the presence of NaCl, $MgCl_2$ and $MgSO_4$ salts in appreciable amounts thereby decreasing the activity coefficient that results increased gypsum solubility leading to higher reclamation efficiency over mined gypsum (ICAR-CSSRI, 2017). Since combined availability of PG and MG in India is comparable to that of the total available mined gypsum (IBM, 2015), so there is need for systematic studies with convincing evidence that can pave the way for their large scale commercial use in sodic soil reclamation. Jha *et al*. (2020) reported that 50GR MG and 25GR GYP+25GR MG can substitute 50 GR GYP for the reclamation of sodic soil without compromising rice and wheat yield besides improving soil properties.

## Alternate Land Use Systems

Planting trees is a viable option for those situations where salt affected soils cannot be reclaimed through conventional techniques. At ICAR-CSSRI, for commercial cultivation in salt-affected soils, a number of salt tolerant agro-forestry and fruit trees, shrubs, grasses and medicinal and aromatic plants have been identified. Some of the promising agro-forestry species are *Prosopis juliflora, Acacia nilotica, Tamarix articulata and Casuarina equisetifolia*. In high pH soils, for sustained fuel wood and forage production, *Prosopis juliflora-Leptochloa fusca* system has been found promising (Dagar and Tomar, 2002). Appropriate planting techniques have been standardized for raising tree plantations in saline (sub-surface planting, ridge-trench method, subsurface planting and furrow irrigation system) and sodic (ridge-trench method, auger-hole method, pit auger-hole method, pit-auger hole and furrow method) soils. Different fruit-based agro-forestry systems, with bael (*Aegle marmelos*), aonla (*Emblica officinallis*) and karonda (*Carissa karodus*) as tree components and cluster bean (in *Kharif*) and barley (in *Rabi*) as subsidiary components, have been found practically feasible and Remunerative. Several researchers had shown that growing trees has the potential in reclaiming calcareous sodic soils with or without chemical amendments application (Garg, 1998; Singh *et al*., 1994; Dagar *et al*., 2001a, b; Dagar and Tomar, 2002; Dagar, 2005; Singh, 2009; Dagar *et al*., 2014; Dagar and Minhas, 2016; Dagar *et al*., 2016).

Adoption of alternate land use systems in salt affected soils not only rehabilitate the salt affected soils but also serve many ecosystem functions such as sequestration of atmospheric $CO_2$ at the same time ensure livelihood security of the resource poor famers. Datta *et al*. (2015) measured the distribution of organic carbon pools under different land uses namely guava, litchi, mango, jamun, eucalyptus, prosopis and rice-wheat cropping system in a reclaimed sodic soil and found higher efficiency of guava plantation in sequestering SOC (133 Mg C ha$^{-1}$) and also in passive pool (76 Mg C ha$^{-1}$) at 2.0 m soil depth (Fig. 1).

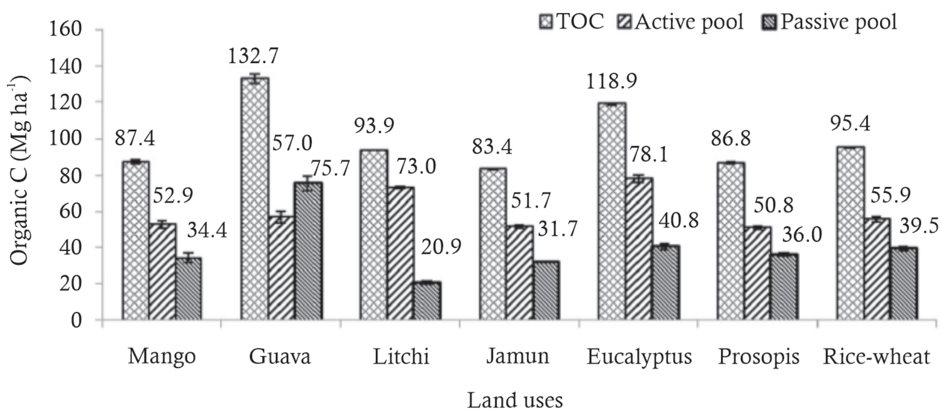


**Fig. 1.** Overall SOC storage into different pools under different land uses in a reclaimed sodic soil. Vertical bars indicate ±S.E. of mean of the observed values (Datta *et al*., 2015)

Garg (1998) evaluated SOC build up in an alkali soil under four tree land uses (acacia [*A. nilotica* (L.)], shisham [*D. sissoo*], mesquite [*P. juliflora*], and arjuna [*T. Arjuna*]) and showed that shisham and mesquite recorded higher organic C with higher microbial activity in upper 60 cm soil depth resulting from decreasing $Na^+$ levels in soil and facilitates the conversion of leaf litter to soil organic matter. Carbon sequestration rate was 0.2–0.8 Mg C ha$^{-1}$year$^{-1}$after 20 years of planting of different trees species in an alkali soil with maximum C sequestration under *Prosopis juliflora* (9.3 g kg$^{-1}$) (Fig. 2) (Singh and Gill, 1990).

## Other Industrial by-products

Industrial by-products such as pyrite, elemental sulphur, fly ash, press mud and distillery spent wash have been used for reclaiming sodic soils. Due to slower oxidation and heavy metals presence, the use of pyrite is restricted from widespread adoption by farmers despite certain beneficial effects of pyrite. In order to be as effective as soluble calcium salts, soil applied sulphur must undergo oxidation to generate sufficient sulphuric acid for replacing the exchangeable $Na^+$. Recent study

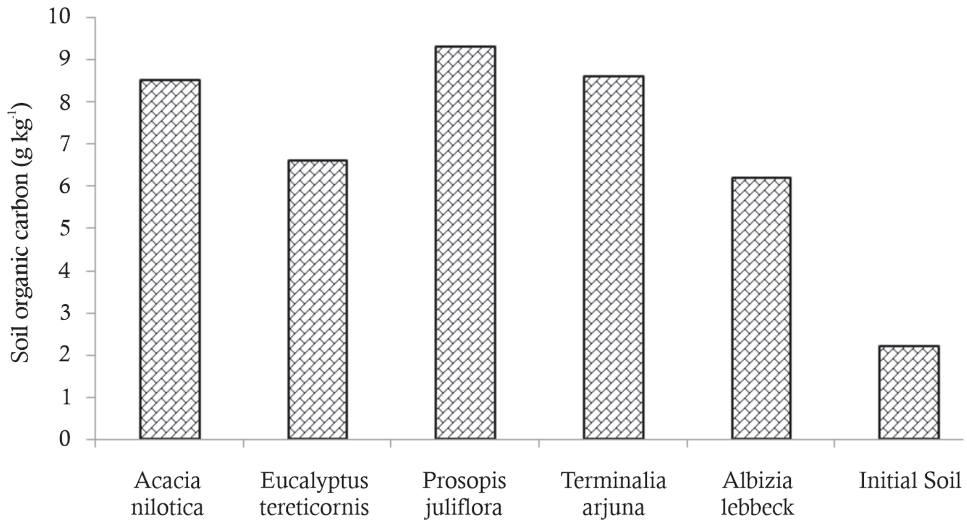


**Fig. 2.** Ameliorative effect of 20 years old tree plantations on soil organic carbon enrichment at 0–15 cm of an alkali soil (Singh and Gill, 1990)

indicates that different combinations of Reliance Formulated Sulphur (RFS) was as effective as 50% GR in reducing the pH of variably textured sodic soils with RFS applied 21 days before rice transplanting resulting in greater oxidation (ICAR-CSSRI, 2018). Isolation and characterization of effective microbial strains of *Thiobacillus ferrooxidans* and *Acidithio bacillus*, that can hasten the rate of oxidation resulting in improved pyrite efficiency, is the need of hour. Such strains of microbes can also help in improving the efficiency and use of elemental sulphur, a by-product of oil refineries, for sodic soil reclamation. Press mud (PM), being a rich source of plant nutrients, is a by-product of sugar industry with low pH. Acidic sulphitation press mud (SPM) and lime rich carbonation press mud (CPM) are produced when sugar is manufactured through sulphitation and carbonation processes, respectively. These press muds can be used for the reclamation of alkali soils. Studies on supplementing FGD, MG, elemental sulphur, phosphoric acid, pyrites with organic amendments including press mud, distillery spent wash and post methanation effluent for improving their sodic soil reclamation efficiency needs to be undertaken.

## Municipal Solid Waste Compost

For restoration of the fertility of salt affected soils recently municipal solid waste (MSW) has gained importance as an organic amendment. To avoid environmental and health issues associated with the land filling of MSWs, composting of MSW is considered as an important recycling tool. It is found as a relatively low cost and sustainable method of diverting organic waste materials including MSW from landfills while creating a quality product that is suitable for enhancing productivity of salt-affected soils. Meena *et al*. (2016) found that municipal solid waste compost (MSWC) application can increase dissolution of precipitated $CaCO_3$ and soluble $Ca^{2+}$ availability for replacing $Na^+$ from soil exchange complex, activity of many soil enzymes (dehydrogenase, alkaline phosphatise and urease), microbial biomass carbon and nutrient availability in a saline-sodic soil. Recently Sundha *et al*. (2020) reported that combined application of GR25% and compost prepared from municipal city waste was efficient in reducing pH and EC of saline-sodic soil. However, MSWC application may sometimes inadvertently increase heavy metal concentrations, suggesting the need for systematic field experimentation and laboratory analysis to ensure the safe field application.

## Saline Soil Management

Rise in water table and soil salinization took place due to commissioning of irrigation projects without adequate drainage facilities. Such degradation is common in the Mediterranean Basin, Indo-Gangetic Plains and the Murray-Darling Basin. For maintaining regional salt and water balances, there is a need for judicious use of irrigation water, adoption of improved irrigation practices and adequate drainage, but site specific drainage interventions are also necessary for rehabilitating the waterlogged salty lands.

## Sub-surface Drainage

For controlling water logging and soil salinity, subsurface drainage (SSD) is provided by maintaining the water table at a specific soil depth. It consists of a network of concrete or PVC pipes having filters installed manually or mechanically at a design, spacing and depth below soil surface to control water table depth by draining excess water and disposing it out of the area by gravity or by pumping from an open well (sump) (Fig. 3). There are some socio-economic issues that constrain the success of SSD projects besides its efficiency in reduction of waterlogging and salinity and improvement in crop yields. SSD is actually a community-based programme than the other individual farmer based salinity mitigation technologies. In many areas, lack of community response makes continued operation of SSD very difficult in addition to its exorbitant initial investments necessitating for public-private partnerships to reduce the establishment costs and making awareness campaigns for sensitization of the community for long-term benefits (Ritzema *et al.*, 2008). In landlocked SSD areas situated away from the seas, an important limitation is the safe disposal of saline drainage effluents. Site specific suitable models comprising intergradations of SSD with bio-drainage using high rate transpiring plantations, evaporation ponds, and judicious alternate use of saline and fresh waters, salt tolerant crops cultivation and saline aquaculture can be developed which can partly overcome this problem. In addition, there is a need to assess and standardize the regulated drainage and solar powered pumps for pumping of effluents for site specific situation. Waterlogging and salinity are essentially regional problems so regional modelling studies should be focussed instead of site specific experiments which would be helpful in drawing valid conclusions on the nature and extent of the problem and devising appropriate benchmarks for the cost-effective management of salt and water balances.

**Fig. 3.** Installing subsurface drainage in saline soil (Photo Credit: ICAR-CSSRI, Karnal)

## Low Cost SSD using Cut Soiler with Crop Residues as Drainage Material

Recently research on this aspect is started at ICAR-CSSRI in collaboration with Japan International Research Centre for Agricultural Sciences (JIRCAS). Higher drainage intensity is often required during initial land reclamation of saline soils for quick leaching of salts from the soil profile; however, higher cost is involved as the drainage pipes are placed at closer spacing. For such needs of initial drainage, lower initial costs and a healthy soil environment, an inexpensive degradable organic subsurface drainage material is required. Straws of cereal crops are porous organic materials with certain strength and endurance. In JIRCAS project, crop residues are used to make channels at 50 cm soil depth with the help of cut soiler (Fig. 4). The saline water is drained out from the surface making the soil suitable for crop growth. Very little research has been conducted on this aspect. Yadav *et al*. (2021) showed that rice straw residue and gypsum placed at 40 cm depth reduced subsurface sodicity (ESP) by 31, 23 and 4% at lateral distance of 0.30, 0.60 and 1.25 m, respectively. Grain yield of rice and wheat also increased with decreasing Cut-soiler spacing. The respective increase in rice and wheat yields were 17.7 and 18.3 % in 2.5 m and 7.6 and 10.8 % in 5.0 m spacing, respectively over control. Lu *et al*. (2018) explored the potential of using bundled maize stalks and rice straws as subsurface drainage material in place of plastic pipes. Large lysimeters filled with coastal saline soils and planted with maize, the drainage performance of the two organic materials were tested in comparisons with conventional plastic drainage pipes. During the maize growing period, distribution of soil moisture, change in soil salinity with depth, and the crop growth were monitored in the lysimeters. Compared to the plastic drainage pipes, maize stalk and rice straw drainage were more efficient in leaching salt and water from the maize root zone. These organic materials increased drainage rate, leaching fraction, and lowered water table; and salt stress in the maize root zone were lowered due to their efficient drainage processes with slightly higher level of maize biomass. Therefore, straws of cereal crops may serve as an excellent organic substitute for the plastic pipes in the initial stage of saline coastal soil reclamation. These organic substances after decomposition improve the soil quality through sequestering carbon in soil in more stable forms at lower soil depth.

## Salinity Modelling

In Indian conditions, modelling salinity has hardly been explored. In saline soils, a dynamic and transient condition explains salinity. Soil salinity, sodicity and salt leaching to drainage water in

**Fig. 4.** Cut-soiler in operation in saline soils of Nain Farm, Panipat (Photo credit: ICAR-CSSRI, Karnal)

irrigated fields are influenced by the chemical reactions such as cation-exchange, solubility, precipitation reactions in root zone. Salinity, sodicity, and environmental hazards of drainage water due to irrigation were evaluated by using models (Rhoades and Suarez, 1977; Shahid *et al*., 2013) and the effect of chemical reactions on soil solution composition for transient conditions within the root zone were also calculated. Various limitations might have come across by the salinity models and vulnerabilities are not properly designed and developed according to the First Expert Consultation on Advances in Assessment and Monitoring of Salinisation for Managing Salt-Affected Habitats (Aquastat, 2016). For a reliable soil salinity management scenario, a solid understanding of the dynamic nature of salinity as well as calibration and validation considering soil and crop field data are required and the state of the art physically based water and solute transport models can be considered (Shahid *et al*., 2013). The lack of input data is usually a major constraint of these models (Ranatunga *et al*., 2008), therefore it is advantageous to use simple and more robust forms of models. Leaching Requirement (LR), the amount of water that must infiltrate the root zone to lower the soil salinity within acceptable levels- can be articulated through an easily measurable and robust soil property such as the field capacity and saturated paste water content. The LR component has played an important role on drainage improvements as a direct way by simulating the necessity of drainage.

Many transient LR models based on this concept (e.g. WATSUIT, TETrans) (Corwin *et al*., 2007) have been developed and more advanced software also includes other complex key processes keeping in view the salinity/sodicity issues (e.g. UNSATCHEM) (Shahid *et al*., 2013; Šimùnek *et al*., 1996). For understanding both salinity and sodicity processes, this advanced code has been successfully used at a very local scale (Jalali *et al*., 2008). There are software's for example LEACHM, PHREEQC, HYDRUS, and ORCHESTRA which are not much focussed to soil salinity issues (van Beek and Tóth, 2012). For specific case studies, a range of data driven models have been applied in addition to these models (Patel *et al*., 2002; Zou *et al*., 2010). For secondary salinity applications, Mediterranean countries successfully used the SALTMED LR model (Ragab, 2002) which is the most popular in field applications. Therefore, more emphasis should be given on salinity studies using models in the present context of climate change.

## Saline Effluent Reuse

Areas with fresh water availability while pre-sowing irrigation, combine use of saline and fresh in irrigation is a useful option. Shallow water tables can be partly lowered when saline water is reused in cyclic or blending mode with fresh water. There are reports on recycling of saline effluents for producing many crops such as wheat, pearl millet, sorghum, sunflower, barley, rye grass, etc. which was profitable with only slight to moderate reductions in economic yields using long-term experiments (Sharma *et al*., 2005; Yadav *et al*., 2003, 2007), provided availability of canal water for blending with saline water and provision of few irrigations with fresh water at critical crop growth stages. Cultivation of crops such as *Salvadora* capable of enduring excess salts may further enhance the acceptability of this practice. In poorly drained coastal saline lands, commercial cultivation of high value seaweeds can be a profitable business enterprise (Subba Rao and Mantri, 2006). Land shaping models have been successfully implemented for commercial fish culture in waterlogged salt-affected lands of central Indo-Gangetic Plains and some saline coastal areas of India. However, for making more productive reuse of saline effluents, stage dependent osmotic and matric stress tolerance limits of suitable site-specific crops with optimal irrigation schedules needs to be worked out. Recently Chandel *et al*. (2021) showed that alternate application of saline and fresh water is suitable for higher carbon enrichment and nutrient availability in soil and better yield of seed spices grown in arid and semiarid regions.

## Land Shaping Models

Land shaping is the alteration of the surface of the land primarily for harvesting rain water for creating a source for irrigation, reducing the effect of groundwater salinity, reducing drainage congestion and growing multiple and diversified crops round the year (Mandal *et al*., 2019). Harvesting rainwater in farm pond and raising of low land with excavated soil reduced the impact of saline groundwater table on salinity build up of soil, improved drainage congestion of low-lying land and created irrigation resources for irrigation water starved coastal areas (Mandal *et al*., 2021).

Vast area of sodic soils suffering from waterlogging, with shallow water table (≤2 m) and no response of amendments, suggests the need for standardizing alternative land shaping approaches to improve their productivity (Verma *et al*., 2015). For amelioration of such waterlogged sodic soils, land shaping techniques should be devised for making provision of fish pond and raised land to grow vegetables for higher returns. Similarly land shaping techniques needs to be standardized for flat coastal salt-affected soils with poor water sorptivity and natural drainage, and receiving intense rainfall. Under such conditions, backwater flows may further reduce the efficiency of surface drainage for removing the excess water. For land use intensifications, simple earth replacement techniques such as farm pond and integrated rice-fish cultivation are the promising solutions. Rainwater harvested in these ponds not only reduces the soil salinity but also ensure ample fresh water availability for irrigation to the winter season crops (Mandal *et al*., 2017).

## Plant-based Solutions

For improving the productivity of salt-affected soils, plant-based approach such as growing salt tolerant crops and cultivars is an adaptive way. Now a day for varietal improvement and screening trials, molecular techniques have become an integral part. Through conventional and marker-assisted breeding approaches, genes and molecular traits responsible for salinity tolerance can be identified and incorporated into popular salt sensitive cultivars. In sodic soils, three fourths of reclamation costs can be saved when amendments and salt tolerant cultivars were used in combination and acceptable crop yields were obtained in waterlogged saline lands. ICAR-Central Soil Salinity Research Institute (ICAR-CSSRI), Karnal, Haryana, a premier Institute in India is working for the last more than five decades to develop farmer's friendly technologies for managing salinity and sodicity hazards. One of these is the development of salt tolerant verities of rice, wheat and mustard. To date, ICAR-CSSRI has developed 7 salt tolerant varieties of rice, 4 of wheat, 3 of mustard and 1 of chick pea. These varieties of rice, wheat and mustard can tolerate pH more than 9.0 and $EC_e$ of > 6.0 dS $m^{-1}$ and therefore, widely adopted by the farmers having salt affected soils in Haryana, Punjab, Uttar Pradesh, Gujarat and West Bengal. The soils where normal varieties cannot survive these rice and wheat varieties produced yield of about 2.0-4.0 t $ha^{-1}$ and 3-3.5 t $ha^{-1}$, respectively. Therefore, farmers of salt affected areas of Haryana and Punjab as well as Uttar Pradesh states of India widely adopted these salt tolerant varieties of rice and wheat and getting income from otherwise barren salt affected soils. Tangible improvements in soil quality may be achieved over time when several tree, shrub and grass species were grown in agro-forestry and agri-horticulture systems in addition to producing stable yields of cereal crops.

## Disposal of Sewage Effluents in Tree Plantations

In pisciculture and irrigation of perennial tree crops mostly planted for fuel and timber purposes, treated sewage effluents can be utilized (Kamyotra and Bhardwaj, 2011). For disposal of waste water, certain agro-forestry plantations are considered as a safe sink. Short rotation fast growing tree species such as *Eucalypts*, *Populus* and *Salix* can provide socio-environmental benefits in terms of fuel, timber and carbon sequestration in soil and above ground biomass besides remediation of the wastewater contaminated soils (Rockwood *et al*., 2004). The capacity of the trees in wastewater removal is greatly influenced by different design and management factors like rotation period, water and nutrient needs, and tolerance to salinity and heavy metals. Site- and tree- specific irrigation methods and water quality guidelines should be developed for the best results. There is a need for environmentally-safe irrigation methods to ensure that nutrient additions through wastewater synchronise the plant needs thereby preventing the leaching of excess nutrients to the groundwater posing pollution risks.

## Improved Irrigation Methods

Climate change impacts in the form of high temperature, erratic rainfall and reduced river flows are affecting fresh water supplies severely in many parts of the world. These inevitable changes in land and water use dynamics imply that agricultural production will have to increasingly depend on poor soils and waters. Currently farmers in several areas of India are compelled to utilize low quality water in irrigation and soil reclamation. Under such situations, a well-planned strategy including combination of low water requiring crops in the existing cropping systems, salt tolerant cultivars, application of amendments and micro-irrigation techniques with higher water use efficiency are very much essential. Crop water use efficiency and salt accumulation in soil are governed by method of irrigation, an important factor. For uniform application of water, pressurized methods of irrigation i.e. sprinkler and drip are increasingly used thereby curtailing the water wastages and ensuring adequate leaching; especially in areas with poor drainage. For achieving sustainable higher water use efficiency, agro-edaphic conditions specific suitable irrigation water quality guidelines should be developed for micro-irrigation methods.

## Conclusions

Sustainable use of land and water resources is the top priority to combat land degradation and desertification and the important component of UN Sustainable Development Goals (SDGs). Physical and chemical degradation of millions of hectares of potentially arable lands across the world takes place due to excess salts in soil and water. However, during the past few decades the problem has attained alarming proportions in many irrigated basins like the Mediterranean Basin, the Indo-Gangetic Plains and Murray-Darling Basin. For reclaiming and managing these salt-affected soils and poor quality waters, several efficient solutions have been developed but there is a need for continuous evolvement of new site specific low cost practically feasible strategies to manage the dynamic nature of salinity/sodicity problems.

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# Drone Technology for Smart Agriculture

**Rabi N. Sahoo*, Shalini Gakhar, Ranu Bhardwaj,
Rajeev Ranjan and Sunny Arya**

*Division of Agricultural Physics, ICAR- Indian Agricultural Research Institute, New Delhi-110012*
**Email: rabi.sahoo@icar.gov.in*

**ABSTRACT**

In the present era of information technology, amalgamation of sensors, satellites, digital technology, and robotics is the need of the hour for paving the way for precision, profitable and environmentally safe farming. Recent technological advancement of aerial robot, commonly known as Unmanned Aerial Vehicle (UAV) or Drone, may be boon for smart and precision management of farming. Major potential areas for drone applications in agriculture majorly are mapping, monitoring of crop conditions and some crop managament operations. Aerial sensing from drone bridges the gap between ground-based observations and remotely sensed imagery from conventional aircraft and satellite platforms. This article aims to provide an insight on drones, as an emerging platform for multitude applications for smart agriculture.

**Key words:** Drone, smart farming, remote sensing

## Introduction

Smart agriculture emphasises on congregating Internet of Things (IoTs), artificial intelligence, big data, cloud-based computing under a single parasol (Wolfert *et al*., 2017). Automating the manual tasks such as weeding, spraying, moisture sensing, vigilance, irrigation, decision making etc. can be achieved through multiple sensors, devices, robots and drones. In order to maintain a balance between rising demand and declining supply, modern farming practices are at a pinch. Notwithstanding the enormous contribution, India needs to enhance the effectiveness in the field to utilise its highest potential. Agronomists from all parts of the globe are shouldering responsibility of realisation of "Farm to Fork" model which enables end-to-end delivery, ensuring sustainable supply of food. However, unsuitable approaches of irrigation, crop monitoring, nutrient supply, pesticide spray etc. add new layers of challenges leading to low yield. Furthermore, changing weather conditions, soil deterioration, lack of water supply equally contribute towards hampering the crop growth. In recent years, use of drone technology in agriculture has been exponentially increased as it has led to less man-power cost, thereby increasing the yield.

DRONE stands for Dynamic Remotely Operated Navigation Equipment and is an unmanned aircraft, formally known as Unmanned Aerial Vehicle (UAV). Drone may be considered as a robot which is remotely controlled using software generated flight plans in association with mounted sensors of interest and external GPS (Global Positioning System). Originally drones were used for defence purposes and built for military use. Apart from this, the major role was weaponism and aerial missile deployers. Recently, drones are used for multiple civilian applications like aerial photography, shipping, search and rescue, weather forecast etc. However, drones extend their scope over agricultural domain also, aiding in precision agriculture. Major potential areas for drone applications in agriculture include (i) mapping (Ren *et al*., 2020) (ii) monitoring of crop conditions

(Ahirwar *et al*., 2019; Korobiichuk *et al*., 2018) and (iii) some crop management operations (H. Iost Filho *et al*., 2020). Aerial sensing from drone bridges the gap between ground-based observations and remotely sensed imagery from conventional aircraft and satellite platforms. Drones have been identified as a viable substitute and/or compliment to remote sensing platforms for agricultural applications and mainly for better visualization and quantitative assessment of crops condition at very high resolution.

Aviation and other relevant authorities elsewhere in the world are now allowing drones to be used for limited and specific trials and, in some cases, commercial operations in agriculture, horticulture, viticulture and forestry. Spraying for disease, weed and pest control, spreading micro-granular pesticides and fertilizers and even beneficial insects as well as planting new are among the diverse uses now being found for drones. Vegetation indices can directly tell the crop health status and are widely in use to estimate the structure of vegetation and physiological parameters like-biomass, leaf area index (LAI) and chlorophyll status (Bukowiecki, 2020). Low altitude acquired data can be used for the prediction of Water Use Efficiency (WUE) and Nitrogen Use Efficiency (NUE) throughout the season. It can also be used to monitor the crop efficiency under control, Nitrogen and Water dosages (Yang, 2020). Nitrogen status monitoring is very much important for farmers as it leads to an efficient fertilizer application (Lee, 2020). Spectral reflectance data at different stages of crop growth- LAI, Leaf Dry Matter (LDM), Plant Dry Matter (PDM) and three Nitrogen indicators i.e. Leaf Nitrogen accumulation (LNA), Plant Nitrogen accumulation (PNA) and Nitrogen Nutrition Index (NNI)) have been measured simultaneously, and the relationships between the spectral data and vegetation indices are also developed (Jiang, 2020). UAVs are suitable for monitoring small to medium sized fields. The key advantages are, their flexibility and capability to get the high spatial and temporal data. However, the initial finances and knowledge related investments, further time needed to acquire and process the remote sensing data is high (Jr., 2018). The article aims to introduce status of drone remote sensing with respect to India and overseas, highlighting some of the recent case studies. It also emphasises various research gaps and the opportunities to be considered with respect to usage of drone in agricultural field. Expounding multiple applications, it introduces the updated drone policy along with propositions to introduce private-public partnership.

## Drone Technology

### *Principles of Drone*

UAV's may be classified as Fixed wings and multi-rotors. Fixed wing drones have wings similar to normal aircraft, they save energy during flight hence longer flight time, therefore they are suitable for large area analysis. Multi-rotors include: three rotors called tricopter, four rotors called quadcopter, six rotors called hexacopter, eight rotors called octocopter. They have limited flight time, endurance and speed. Their working principle vary according to their built.

The fixed wing drone derive its lift using the special air-foil shaped wing. The wings are flat at based while curved on top tapering at one end. The unique shape causes differential air steam speed above and below the wings. Bernoulli's principle explains "an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy". The upper air moves with higher velocity relative to the air stream in downside of wings. It ultimately results in development of net pressure gradient in upward direction producing lift for the fixed winged aircraft. However multi-rotor drone derives its lift by the use of fast-moving propellers. The fast-moving fixed pitch propeller produces a downward stream of air which according to Newton's law of motion produces thrust. When the thrust becomes more than the weight of the drone and payload, then it produces lift. Once the drone is up in the air, it can be maneuverer to produce multiple dynamic movement. The dynamic moving is possible due to the added electronics component called electronic speed controllers (ESCs) in the drone to control motor speed. The differential regulation of motor speed produces net thrust in different direction making it very agile once it is in air.

### *Drone Remote Sensing*

Drone is an airborne platform giving a bird's eye view for the area under consideration exploiting rich spatial resolution. According to Food and Agricultural Organisation of United Nations, "The adoption of modern technologies in agriculture, such as the use of drones or unmanned aerial vehicles (UAVs) can significantly enhance assessments of risk and damage and revolutionize the way we prepare for and respond to disasters that affect the livelihoods of vulnerable farmers and fishers and the country's food security." Flexible, low-cost, and high-resolution remote sensing systems that use drones as platforms are important for filling data gaps and supplementing the capabilities of crewed/manned aircraft and satellite remote sensing systems (Tang, 2015). Generally, drone remote sensing has some pre-requisites before flight in terms of site examination, flight planning, sensor mounting and integration. Resultant imagery depends upon multiple scene related parameters, such as illumination, background characterisation, altitude of drone, speed, wind conditions etc.

A standard architecture of drone consists of a flight controller and Electronic Speed Controller (ESC) as main components. Inside the flight controller, Micro Controller Unit (MCU) along with Inertial Measurement Unit (IMU) are integrated. Angles like roll, pitch and yaw are used to represent the movement associated with the drone with the goal of keeping it in its orientation.

There are multiple types of sensors that can be mounted on DRONE depending upon the application and utility. Particularly, RGB, multispectral, hyperspectral, thermal and LiDAR sensors are integrated with drones for agricultural applications (Refer *Figure 1*). Human eyes are sensitive to the red, green and blue bands and mostly standard drones come with the RGB imager. So that drone captured RGB images which recreates the images as our eyes see in reality. Multispectral sensor captures the imageries having visible, near infrared and shortwave infrared wavelengths of electromagnetic spectrum. Different ground objects reflect differently for all the bands. There are many multispectral sensors which can be mounted on the UAV and are capable to acquire the multispectral images, few multispectral sensors available for commercial and research purposes are Red-Edge MX Micasense, ALTUM Micasense, Parrot sequoia, sense fly etc. Thermal cameras have demonstrated high potential for the detection of water stress in crops due to the increased temperature of the stressed vegetation (Daponte, 2019). FLIR Vue pro R, Zenmuse XT are some examples of thermal cameras. Hyperspectral sensors record reflected electromagnetic energy from the Earth surface across the electromagnetic spectrum extending from the visible wavelength region through the near-infrared and mid-infrared region in hundreds of narrow contiguous bands. For example: Nano Hyperspec, Golden Eye etc. LiDAR stands for Light Detection and Ranging that uses distance measuring imaging technology in which light pulses are sent in form of laser beam from ultraviolet, visible and infrared portions of the electromagnetic spectrum. These pulses reflect from target by backscattering. Leica SPL100, Velodyne LiDAR sensors are for mounting on drone.

Drone is an airborne remote sensing platform giving a bird's eye view for the area under consideration exploiting rich spatial resolution. The general procedure of a successful flight includes, (i) Drone and its calibration, (ii) Sensor calibration and integration, (iii) Mission Planning, (iv) Image

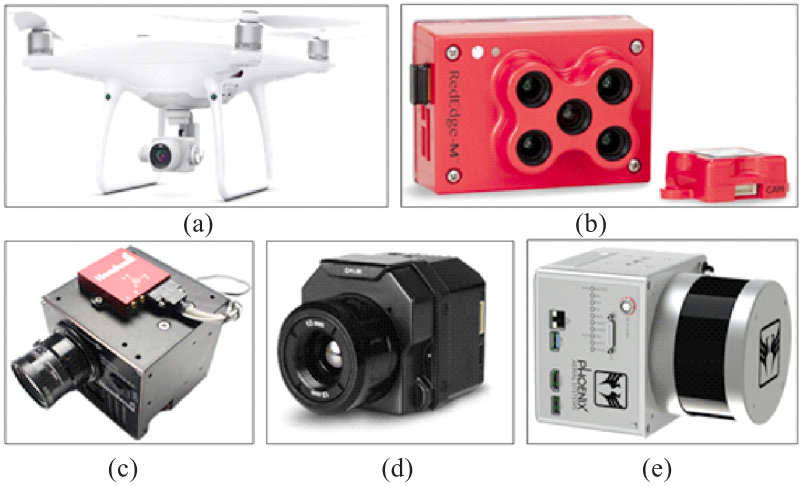


**Fig. 1.** Sensors (a) RGB, (b) Multispectral, (c) Hyperspectral, (d) Thermal, (e) LiDAR

Acquisition (v) Image transfer (vi) Pre-processing (vii) Image post-processing and analysis. The flow diagram of the process is shown in Figure 2.

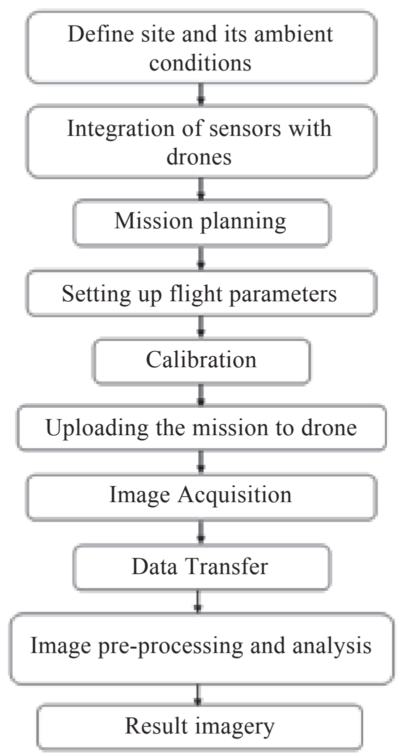


**Fig. 2.** Flow diagram of Drone data processing

## Drone Remote Sensing for Smart Agriculture

India sovereignties the world by producing rice, wheat, pulses, spices etc., adding a generous value to the global economy in the agricultural sector. But, increase in population has played a havoc on agricultural produce, thereby urging for sustainable development. In order to maintain a balance between rising demand and declining supply, modern farming practices are at a pinch. Notwithstanding the enormous contribution, the country needs to enhance the effectiveness in the field to utilise its highest potential. Agronomists from all parts of the globe are shouldering responsibility of realisation of "Farm to Fork" model which enables end-to-end delivery, ensuring sustainable supply of food. However, inapt approaches of irrigation, crop monitoring, nutrient supply, pesticide spray etc. add new layers of challenges leading to low yield. Furthermore, changing weather conditions, soil deterioration, lack of water supply equally contribute towards hampering the crop growth.

India has launched NETRA developed by DRDO with IdeaForge light weight autonomous UAV for surveillance and reconnaissance operations equipped with thermal camera communication system (Gopalaswami and Reddy, 2013). The NETRA has been deployed and utilized in Uttarakhand disaster, Nepal Earthquake, Chennai Flood, Pune landslide, Pathankot attack, Indore traffic management. Agriculture Insurance Company of India (AIC) has conducted a few pilot studies in parts of Gujarat and Rajasthan to see how drones can be useful to insurance companies in settling claims by providing precise and timely status of crops and mapping extent and level of damage due to various calamities (Gulati *et al*., 2018). Maharashtra government is attempting drone technology to assess crop losses due to deficit rainfall in Marathwada region (MeitY, 2018).

Getting timely and accurate data at farm level has been a major problem for the Government Departments for timely settlement of claims to farmers during major calamities like cyclone, hailstorms and floods. Recently, Ministry of Agriculture and Farmers Welfare launched a new program "Kisan" (Crop Insurance using Space Technology and Geo-informatics) on a pilot basis (Aggarwal *et al*., 2016). The data collected by drones is being collated with data obtained using satellite imagery, and traditional crop cutting experiments to arrive at a fool proof conclusion that can be used in settlement of crop loss claims by individual farmers. Indian Council of Agricultural Research (ICAR) is also exploring the possibility of deploying sensor on drone-based platforms for soil and crop condition monitoring (Figure 3) (Sahoo *et al*., 2019). ICAR-Indian Agricultural Research Institute (IARI) is working in a collaborative with many other research institutes to develop indigenous prototype for drone-based crop and soil health monitoring system using hyperspectral remote sensing (HRS) sensors. The hyper-spectral remote sensing technique provides opportunities to develop hand-held devices for non-invasive and rapid soil testing in the proximal sensing mode.

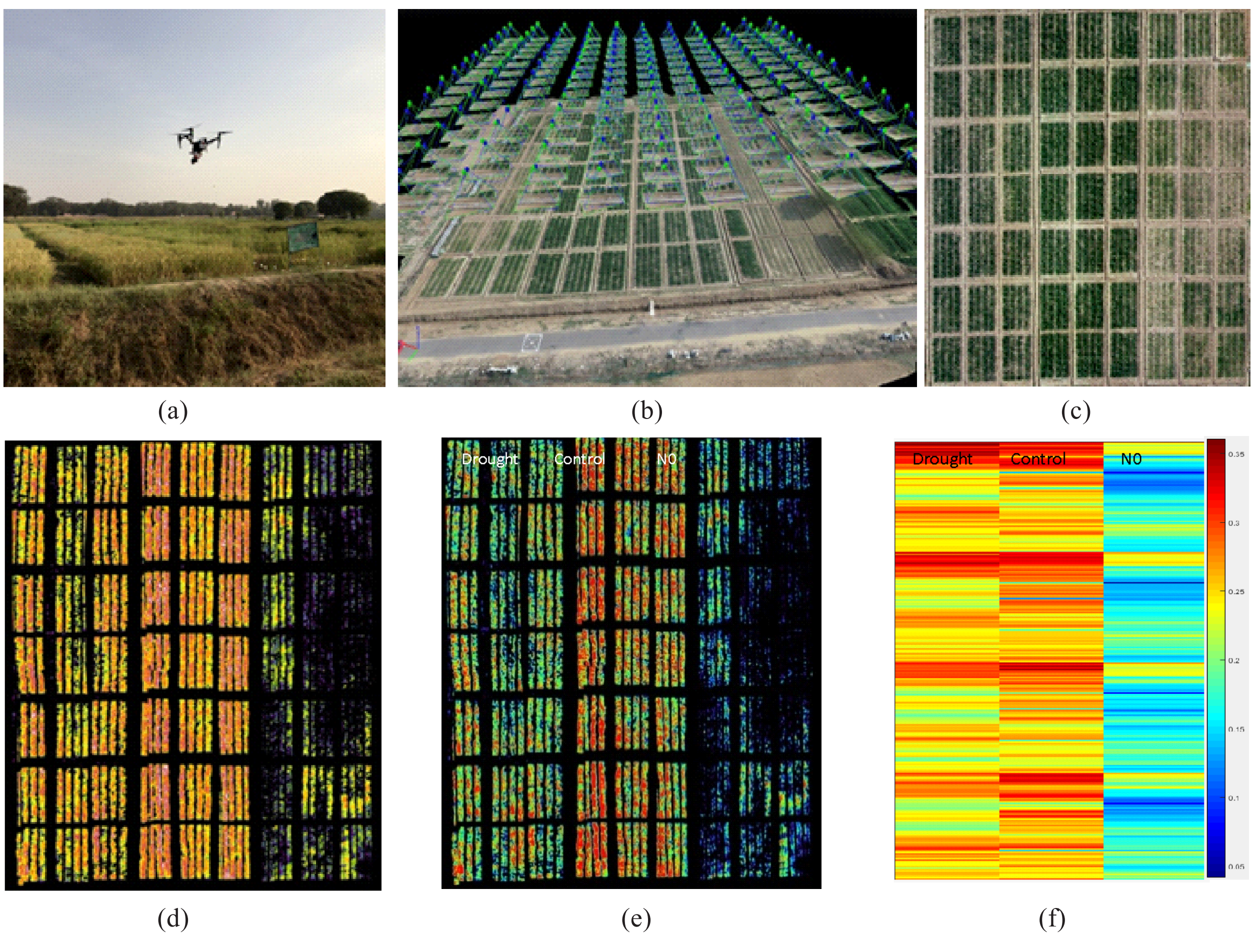


**Fig. 3.** Drone Remote Sensing (a, b, c) drone data acquisition in wheat field of IARI (d) processed NDVI image from multispectral sensor (e) h-NDVI image from hyperspectral image and (f) heat map of different wheat genotypes generated from processed remote sensing indicators for different stress

Its inclusion in the airborne/satellite platform has great potential to augment the capability of remote sensing as a method of assessing soils and crops with greater spectral resolution than the existing multispectral sensors (Aggarwal *et al*., 2016).

## Drone as Variable rate technology (VRT) for Smart Agriculture

Capturing the spatial variability using drone as platform is ongoing at a fast pace. However agronomic response to the captured variability is necessary for input resource, optimization. GPS guided drone equipped with actuators and automated sprayer is becoming the new robot for implementing variable rate technology. It is set to replace human manual labour in smart farms and revolutionize the way we conduct agronomic procedures. The budget 2022 speech also revealed the government's resolve to promote "kisan drones" for various farm operations. Under Ministry of Civil aviation new office "Drone Shakti" has been setup to promote start-up for Drone based hiring services to further reduce cost and dissemination of technology. The success of Drone as variable rate technology has been reported by KVK-Kumarakom which used drone to spray micronutrients and bio-control agents in 10 acres of land effectively (Figure 4). Many drones have been assembled to achieve the specific task of spraying for example, in one of the research work 5L tank capacity with high precision GPS for autonomous spraying drone (Garre, 2018). The variable rate technology help to manage resource use efficiency.

**Fig. 4.** Drones for spraying (Source: Agricultural Wonder Drone)

Remote sensing index images example mid-season NDVI data from drones was used to produce variable rate fertilizer application maps in wheat (Christensen, 2019). Enhanced quality as well as yield of wheat by 50% was seen in a study with the introduction of variable rate application technology (Nakshmi, 2020). For single UAV endurance time and need to swap batteries can become a big constraint. To overcome these problems and achieve faster spray time swarm drone-based approach can be used (Amarasinghe, 2019). Pollination is crucial for development of flower to seed. Heavy use of insecticide is lowering the number of pollinators causing problem of insufficient natural pollination. To combat this problem UAV can be used for supplementing pollination in field (De Silva, 2016). Improved seeding rate and yields of the supplementary pollinated field was observed in hybrid seed production (Liu, 2017). Seed sowing is basic agricultural operation and uniformity of broadcasting ensures proper crop stand. UAV mounted seed spreading nozzle was accomplished using half 1.5-liter bottle as container to disperse 2 kg seeds load for sowing seeds in paddy fields (Dampage 2020).

Drone with high density RGB cameras and other sensors like thermal and multispectral can be used for various mapping purpose. As shown in Figure 5, sowing aberrations of agricultural crops is usually occurring frequently in India due to Early-season agricultural droughts and /or prolonged flooding. Drone based assessment of area affected and classified into prevented and failed sowings can be done at even village level (Stroppiana *et al.*, 2018). A very important use of an early data on prevented sowing and failed sowing will have a tremendous impact on planning for seed distribution for shorter duration varieties and crops in drought affected areas if the monsoon picks up subsequently, planning irrigation schedules and advance preparation of post monsoon compensatory crops (Lieder and Christoph, 2021). Scope for using UAVs can be used to general accurate cadastral level maps, thus enabling accurate area estimation based on latest data rather than old data from revenue department. UAV may provide evidence-based data, which when automated will remove bias in the area estimation exercises. Crop Cutting Experiments (CCE) sites can be monitored at a close range by using UAVs for capturing video footage / images.

**Fig. 5.** Drone for sowing (Source: International Forest Industry)

The drone-based sensing technology would enable rapid, non-invasive, reliable appraisal of crop conditions (nutrient, water, pest and disease stresses) at field scale and would help subsequent issuance of advisories for counter impending environmental and economic consequences of indiscriminate use of fertilizers and other ecologically unfriendly agronomic interventions (Rachman *et al.*, 2019). Drones available in market commonly can carry sensors like high density visible camera, low to moderate resolution thermal and multispectral sensors which are mostly used for retrieval of biophysical and biochemical parameters of plants for monitoring its growth condition and health (Lockie *et al.*, 2020).

Abnormal weather events in the form of excess rainfall, winds and cyclonic storms are being reported frequent occurrence on standing field crops leading to agrarian crisis in different parts of the country (Bueno *et al.*, 2021). Localized risks like hailstorm, windstorm, landslides, etc., certain mid-season adversaries like pest/ diseases and post-harvest losses owing to unseasonal rainfall or natural calamities could still affect crops at any stage of its growth (Chen *et al.*, 2019). Drone remote sensing using high resolution camera can be used for assessing such damages with finer details (Yuan *et al.*, 2021). Crop identification and area determination requires approximately 20-30 cm resolution image whereas, for crop damage assessment within farmers' field due to lodging etc. may require resolution of 3-5 cm. Drone found to be best solution addressing these issues. Such monitoring system will have to be linked with advisory systems too for remedial actions whenever possible.

Drones can be operated over wet fields and tall crops where no machine could normally move, fly quickly to exact locations to treat target areas precisely, as well as be pre-programmed to navigate their own way around (Spoorthi *et al.*, 2017). Their spray process begins with remote crop scouting targeting treatment areas that are followed by applications on a pre-programmed route. And this, can not only be achieved remotely, but also truly autonomously (Klauser and Dennis 2021). Drone-based spraying option, avoids manual options of sanitization with zero risk. This is faster than manual spraying, covers greater area with better efficiency due to smaller droplet size, can reach areas that are otherwise unreachable, and is very effective on irregular surfaces, garbage dumps, etc (Talaviya *et al.*, 2020). The spraying can be quick and focussed, on critical 'hotspots (Devi *et al.*, 2020). The number of human lives that could also be protected through drone-based sanitisation is potentially huge, given large population in India. Typically, one hour of drone disinfectant-spray is equivalent to the spraying carried out all day by 6 to 8 manual operators in an open space, and 3 to 4 operators in an urban environment where the drone flies at relatively low speeds.

## Challenges and Opportunities

The modern farming industry is at a turning point. With the development of more advanced farm management techniques, such as precision agriculture, industry professionals now have more tools than ever to improve the accuracy and efficiency of processes. The use of the different types agricultural drones for solving specific tasks of plant growing is studied: creation of electronic maps of fields, operational monitoring of crop conditions, evaluation of germination and predicting crop yields, checking the quality of ploughing, maintaining environmental monitoring of agricultural land, etc. Consequently, drones are very important tools in the modern agriculture and farming systems.

For young entrepreneurs it is a business opportunity to operate Drones for spraying services in agriculture in addition to its advanced use. It is predicted that this technology can engage a new generation in agriculture and will hopefully reverse the trend of deflection from farms located in the fields.

### *Technological point of view*

Technical glitches are involved when comes to drone data acquisition, multiple issues like out-of-range error, automatic mode causes accidents. Connection between drone and its accessories operate on special frequencies posing difficulty. Platforms, sensors, operations, and environments all have constraints. Drones are more susceptible to weather and human-related accidents, and therefore, may incur potentially large expenses due to damage. UAV hardware is needed to be graded with appropriate IP rating to be operable in diverse conditions. One of the major gaps lies in adopting UAV is their deployment at the required scale. An approximate calculation indicates requirement of 2000 UAVs for 60 days for one time data acquisition of whole kharif net sown area (for 108mha) of country if rate of area coverage by UAV is 10 $km^2$ per day. UAV can be used only in complementary to high resolution satellite data whenever and where ever it is required.

### *Application point of view*

Protocol of drone data acquisition (radiometric consistency, time of observation, bands, band widths, spectral / radiometric resolution) needs to be worked out keeping in view crops and locations of operation (Dayoub *et al*., 2020; Ahirwar *et al*., 2019). Post-processing of UAV captured high resolution imaging data leads to generation of huge volumes of raster data which poses challenges in terms of storage as well as processing for geo-referencing, mosaicking visualization etc (Tang *et al*., 2021). Weather conditions are likely to have impact on the UAV equipment.

Most of the UAV models available are assembled from modules which are generic in nature, thus limiting application development. Well integrated UAV using modules specifically designed for agriculture will help extracting full potential of the available technologies (Mairaj *et al*., 2019). Most drones have short flight ranges thus limiting the acreage that they can cover. The ones with the longer flight ranges are relatively more expensive. Mostly farmlands may not have good connectivity, thus either the farmer has to invest in connectivity or buy a drone capable of capturing data locally for later processing. Options of gasoline operated UAV that can fly for whole day can also be explored to cover very large areas in a day. Technological unawareness may be a hurdle in its penetration as acceptability in farmer's field (Van der Merwe *et al*., 2020).

### *Policy point of view*

Previous DGCA regulations restrict potential use of drone in Indian Agriculture (Singh *et al*., 2019). There should be flexibility to government organizations/ Research Institutes and identified agencies who are involved in developing standard operating procedures (SOPs) for drone technology use in Agriculture (Kumar, 2021). According to Ministry of Civil Aviation, Drone Policy is revised based on a premise of trust, self-certification and non-intrusive monitoring. Several approvals abolished: unique authorisation number, unique prototype identification number, certificate of manufacturing and airworthiness, certificate of conformance, certificate of maintenance, import clearance, acceptance of existing drones, operator permit, authorisation of R&D organisation, student remote pilot licence, remote pilot instructor authorisation, drone port authorisation etc. Interactive drone airspace map with red and yellow zones shall be displayed. No permission required for operating drones in green zones. Import of unmanned aircraft systems shall be regulated by the Directorate General of Foreign Trade or any other entity authorized by the Central Government. This creates an opportunity to promote 'Make-in-India' drones, specific to applications.

## Conclusions

Agriculture provides occupation to supreme population in India, contributing to country's economy. This paper is an aid to researchers, who face multitude of challenges with respect to drone remote sensing. The work delivers an exhaustive review of current usage of drones with respect to its applications in field of agriculture. The study presents a contrast between the traditional and modern approaches of farming including IoTs, artificial intelligence etc. The drone remote sensing expands its scope over applications like, crop heath monitoring, mapping of nutrients in field, spraying of pesticides to remodel to agricultural domain. With updated drone policies and supportive information, the technology may enhance agricultural related applications. The paper might help researchers, start-ups, governmental and non-governmental organisations to enhance their capabilities and prepare them for upcoming challenges. Automated techniques using artificial intelligence make the drone-based infrastructure more effectual to modernise agriculture. Further, associating the private sector with the public organisations may prove to be a virtuous initiative to revolutionise UAV industry in India.

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