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"Strategies for Enhancement of Farmers Income in Dryland Agriculture"

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Feed the Future - India Triangular Training

Editors

Dr. Manoranjan Kumar

Dr. R. Rejani

Dr. K. Nagasree

Dr. B. Krishna Rao

Dr. K. Sammi Reddy

Mrs. V. Usha Rani

Dr. P. Chandra Sekhar

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ICAR-Central Research Institute for Dryland Agriculture
Santhoshnagar, Hyderabad – 500 059
Phone: +91-40–24530177, 241110712
Fax: +91-40–24531802 E-mail : director@icar.gov.in
Website: http://www.crida.in

Course Director	:	Manoranjan Kumar
Associate Course Director	:	R. Rejani, K. Nagasree, B. Krishna Rao, K. Sammi Reddy V. Usha Rani and P. Chandra Sekhar
Editorial Assistance	:	D. Kalyana Srinivas

फोन/Phone : कार्यालय/Off. +91-040-24530177
फैक्स/Fax : 24531802, 24535336
ई-मेल/E-mail : director@crida.in
वेब/Web : www.crida.in

भाकृअनुप - केंद्रीय बारानी कृषि अनुसंधान संस्थान
ICAR - Central Research Institute for Dryland Agriculture
संतोषनगर/Santoshnagar, हैदराबाद/Hyderabad-500 059, भारत/INDIA

डॉ. के. सम्मी रेड्डी
कार्यकारी निदेशक
Dr. K. SAMMI REDDY
Acting Director

FOREWORD

The focus of the agricultural development programmes are not only for increasing the productivity of crops but also for enhancing the income of the rural community through appropriate interventions. Accordingly, the **Feed The Future - India Triangular Training (FTF-ITT)** Program on **"Strategies for Enhancement of Farmers Income in Dryland Agriculture"** in collaboration with **MANAGE** is organized at **ICAR - Central Research Institute for Dryland Agriculture (CRIDA),** Hyderabad from 16 to 30th January 2018. The major goal of this training program is to create awareness among the trainees from ten different countries of Africa and Asia and to make them to understand the scope and potential for enhancing income and livelihood opportunities of dryland farmers through sustainable natural resource management and crop interventions. The present publication is compilation of such strategies needed for the sustainable management of natural resources and crops in a participatory mode. The primary objective is to improve income and livelihoods of dryland farmers through refinement of technological interventions suitable to rural stakeholders.

There is a meticulous effort by the training organizers in documenting the appropriate interventions required for improving the income and livelihood of farming communities in drylands. The publications would be useful for practitioners, researchers, extension personnel and entrepreneurs who are formulating and implementing the development initiatives for income and livelihood enhancement of farmers with a focus on social and technological interventions. The present training course also aims at creating a knowledge platform in order to enable the rural poor for income and livelihood improvements through integrated management of natural resources and crop interventions.

This publication will serve as a ready reckoner intended to build knowledge, skills and enable sustainable livelihood and income for rainfed farmers. This includes practical experiences of ICAR-CRIDA emanated from AICRPDA, NICRA, AICPAM, Contingency, NAIP projects and experiences of other ICAR institutes like Indian Institute of Water Management, Bhubaneswar, Indian Institute of Soil and Water Conservation, Dehradun, Water Technology Centre, IARI, New Delhi and WALAMTARI, Hyderabad which is sure to act as source of inspiration in the direction of improvement in income and livelihood security of dryland farmers.

HYDERABAD
January 30, 2018

K. SAMMI REDDY
Director (Acting), ICAR-CRIDA

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Climate Resilient Agriculture for Sustainable Crop Production

***K. Sammi Reddy, M. Prabhakar and J.V.N.S. Prasad**
*Director (Acting)
ICAR-Central Research Institute for Dryland Agriculture
Santoshnagar, Hyderabad
Email: ksreddy_iiss39@yahoo.com

Indian agriculture, predominantly rainfed, is vulnerable to the vagaries of monsoon. International Panel on Climate Change (IPCC) in its Fifth Assessment Report observed that 'Warming of climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed, the amount of snow and ice have diminished, and sea levels risen. Climate change projections for Indian sub continent up to 2100 indicate an increase in temperature by 2-4^{0}C, with different regions expected to experience differential change in the amount of rainfall. It is evident from the shifting weather patterns in recent years, causing increased rainfall variability (8 out of 15 years drought), heat and cold waves, hail storms, rising sea levels contaminating coastal freshwater reserves and increased frequency of flooding affecting many areas. To meet the challenges of sustaining domestic food production in the face of changing climate and to generate information on adaptation and mitigation in agriculture to contribute to global fora like UNFCC, the Indian Council of Agricultural Research (ICAR) launched a flagship network project '*National Initiative on Climate Resilient Agriculture*' (NICRA) during XI Plan in February 2011, and during XII Plan it is referred as '*National Innovations in Climate Resilient Agriculture*' (NICRA). Major objectives of NICRA project are:

- To enhance the resilience of Indian agriculture to climatic variability and climate change through strategic research on adaptation and mitigation
- To validate and demonstrate climate resilient technologies on farmers' fields.
- To strengthen the capacity of scientists and other stakeholders in climate resilient agriculture
- To draw policy guidelines for wider scale adoption of resilience-enhancing technologies and options

NICRA scheme involves 4 major components, viz., Strategic Research (41 ICAR Institutes), Sponsored and Competitive Grants (18 + 33 Projects), Technology Demonstration (121 KVKs, 25 AICRIPAM, 23 AICRIPDA Centers), Capacity Building and Knowledge Management. In the strategic research, both short term and long term research programs with a national perspective have been taken up involving adaptation and mitigation covering crops, horticulture, livestock, fisheries and poultry. The main thrust areas covered are (i) identifying most vulnerable districts/regions, (ii) evolving crop varieties and management practices for adaptation and mitigation, (iii) assessing climate change impacts on livestock, fisheries and poultry and identifying adaptation strategies. Therefore, continued emphasis will be on enhancing the resilience of Indian agriculture to climate variability and change.

One of the major thrusts of the scheme was to build state of the art infrastructure for climate change research at core institutes. In particular, state of the art research facilities such as High Throughput Plant Phenomics facilities, FATE, CTGC, Eddy Covariance Towers, a network of 100 Automatic Weather Stations, Exclusive Satellite Data Reception System, Rainout shelter facility, Animal Calorimeter, CO_2 Environmental Chambers, Custom designed animal shed, Research Shipping Vessel, etc. have been set up to support strategic research. Significant achievements of the project include extensive field phenotyping of germplasm of target crops (rice, wheat, maize, pigeonpea, tomato) to multiple abiotic stresses, preparation of first ever Vulnerability Atlas of India at district-level for all the 572 rural districts. Large number of germplasm screened for drought, heat, salinity, submergence tolerance etc. in different field and horticultural crops, for identifying donors for stress tolerance. Number of advance breeding materials was generated and evaluated at multi-locations for developing new cultivars. QTL for drought tolerance was introgressed into pusa basmati rice varieties. Two rice genotypes for submergence tolerance was registered with NBPGR. One salinity tolerant variety is in final year of AICRP trials. Three superior heat tolerant hybrids were developed. Four drought tolerant rice varieties were released for Tripura. Two extra-early (50-55 days) green gram varieties were identified for summer cultivation (IPM 409-4, IPM 205-7) and one multiple stress tolerance redgram wild accession (*C. scarabaeoides*). Five heat tolerant and 12 drought tolerant genotypes in tomato. Number of mapping population in rice, wheat, maize were developed for identifying QTL for various abiotic stresses in these crops for utilization in MAS breeding. In Horticultural Sciences Inter-specific grafting technique (tomato over brinjal) for flood and Environmentally safe protocol for induction of synchronized flowering was developed. High Throughput Screening of Germplasm using Plant Phenomics, Temperature Gradient Chambers, Rainout Shelters resulted in Two high temperature tolerant tomato hybrids, IIHR 335, 339; four flood tolerant onion accessions, 1656, W 397, W 441 and Arka Pitamber. Allometric equations developed to estimate above and below ground biomass and carbon in mango.

Under NICRA, emphasis has been placed on the development of technologies which can reduce the green house gas emissions without compromising on yield. As part of this initiative, various ICAR institutes are working on various themes related to the GHG emissions. Facilities like, Eddy Covariance towers are established at IARI, New Delhi and National Rice Research Institute (NRRI), Cuttack for continuously monitoring the GHG emissions from the crop fields during growing season so as to quantify precisely the extent of GHG emissions from the paddy systems. Research Facilities like Rainout shelter, Carbon dioxide Temperature Gradient Chamber (CTGC), Free Air Carbon dioxide Enrichment (FACE), Free Air Temperature Enrichment (FATE) etc. have been established to understand the impact of elevated carbon dioxide (eCO_2) and temperature and develop crop varieties that can withstand these stresses. Practices which can further reduce the GHG emissions such as improved systems of paddy cultivation, fertiliser management, improved fertiliser materials, crop diversification, etc. are explored for further reducing the GHG emissions from the paddy based systems. Natural Resource Management technologies which impart adaptation to climate change include use of Biochar, Conservation Agriculture, water foot prints and emission reduction through efficient energy management, carbon sequestration by agroforestry, techniques for measurement of GHG emissions in the rice-based system and marine ecosystem; carbon sequestration potential through agro-forestry systems across the country have been extensively studied.

The traits identified in indigenous breed viz., heat shock proteins, air coat color, wooly hair etc. that impart tolerance to heat stress could be used in future animal breeding programs to develop breeds that can withstand high temperature. Different feed supplements have been identified and tested successfully to withstand heat stress in cattle. Studies on prilled feeding in cattle showed that they help lowering stress levels and methane emission. Custom designed shelters system and feed supplementation with chromium propionate, mineral supplements (Cu, Mg, Ca and Zn) both in feed and fodder significantly improved the ability to withstand heat stress. Relationship of temperature and spawning in marine and freshwater fisheries sector is being elucidated so that fish catch in different regions can be predicted by temperature monitoring. A shift in the spawning season of oil sardine was observed off the Chennai coast from January-March season to June-July. Optimum temperature for highest hatching percentage was determined in Cobia. A closed poly house technology was standardized for enhancing the hatching rate of common carp during winter season. An e-Atlas of freshwater inland capture fisheries was prepared which helps in contingency planning during aberrant weather. For the first time a green house gas emission measurement system was standardized for brackish water aquaculture ponds. Cost effective adaptation strategies like aeration and addition of immuno-stimulant in the high energy floating feed helped freshwater fish to cope with salinity stress as a result of sea water inundation in Sundarban islands. Relationship were established between increase in Surface Sea Temperature (SST) and catch and spawning in major marine fish species. Simulation modeling was used to understand the climate change and impacts at regional/ national level.

Technology Demonstration Component (TDC) of NICRA aims at demonstration of proven technologies to enhance the adaptive capacity and to enable farmers cope with current climatic variability. Location specific technologies which are developed by the national agricultural research system which can impart resilience against climatic vulnerability are being demonstrated. TDC is being implemented in 100 climatically vulnerable districts of the country through Krishi Vigyan Kendras (KVKs) spread across the country. During the XII Plan, 21 more districts are being added along with 25 AICRIPAM, 23 AICRIPDA villages. A representative village in each climatically vulnerable district was selected for implementation. The interventions are broadly divided in to four modules, natural resource management, crop production, livestock and fisheries and the creation of institutional structures for sustaining the activities envisaged and scaling up of interventions.

NRM interventions included site specific rainwater harvesting structures in drought affected areas; recycling of harvested water through supplemental irrigation to alleviate moisture stress during midseason dry spells; improved drainage in flood-prone areas; artificial groundwater recharge and water saving micro-irrigation methods. Through NRM interventions, over 500 Rain Water Harvesting structures were constructed/renovated/repaired, while 80000 m^3 additional rainwater storage capacity was created through farm ponds alone and the cropping intensity was increased by about 20% in several NICRA villages. Under the crop production module, demonstrations consists of drought and flood tolerant varieties, community nurseries for delayed monsoon, water saving paddy cultivation methods (SRI, aerobic, direct seeding), advancement of planting dates of *rabi* crops in areas with terminal heat stress, frost management in horticulture through fumigation, popularization of location-specific & risk-reducing intercropping systems with high sustainable yield index. Under the livestock & fishery module demonstrations on fodder production, especially under drought/flood situations, improved shelter for reducing heat stress in livestock, silage making methods for storage of green fodder and feeding during the dry season, breed selection and stocking ratios for fish production in farm ponds and monitoring of water quality in aquaculture and Integrated farming system models in diverse agro ecosystems are being taken up. Village level institutional mechanisms such as Village Level Climate Risk Management Committees (VCRMC), custom hiring centers are created for managing infrastructure created and to improve the timeliness of operations during the limited window periods of moisture availability in rainfed areas and to promote small farm mechanization for adoption of climate resilient practices. These interventions helped farmers to reduce the yield losses and enhanced their adaptive capacity against climatic variability.

Outcome of NICRA project supported some of the policy issues in several Sate Governments in the Country like Maharashtra (Broad Bed Furrow Technology), Million farm ponds (Andhra Pradesh and Telangana), Ground water recharge initiatives (Southern states), NABARD action plans, NICRA model village expansion in Assam etc. Vulnerability assessment map is being used by different Ministries and several NGOs/CBOs. GHG inventory by NICRA partner institutes contributes to IPCC-BUR reports. Contingency planning workshops organized every year in different states helps in preparedness to face weather aberrations. NICRA is also contributing to several National missions in India like National Mission on Sustainable Agriculture, Water mission and Green fund.

Climate Change and Water Management Strategies in Rainfed Agriculture

Prasanta Kumar Mishra
Director
ICAR-Indian Institute of Soil and Water Conservation, Dehradun
Email: directorsoilcons@gmail.com

The change associated with climate has never been smooth and likely to be expressed in terms of increased uncertainties and extremities of weather. Increase in global temperature of 0.4–2.6°C and 0.3-4.8°C by 2050 and 2100 respectively as compared to base line period (1961-1990) has been projected (Table.1). The myth of climate change deniers was shaken as 2014, 2015 and 2016 each broke the global surface temperature records. Year 2017 is likely to be second warmest year in recorded history just behind 2016. Atmospheric CO_2 concentration is likely reach 550-800 ppm from the present level of 400 ppm by the end of this century. Though the magnitude of projected change as well as past climate trend is moderate as compared to other part of the world, there is unanimous opinion that tropics will be the first and most to suffer due to climate change. Poor economic conditions of majority of population, higher dependence on natural resources and ecosystem service and relatively narrow temperature ranges are reason for suffering. Increased number of extreme events and uncertainty makes the production highly vulnerable. Number of heat waves witnessed during last 25 years (1990-2015) in tropics has exceeded the number in preceding 70 years. Similarly the number of extreme rainfall events as well as drought has also increased in recent past. Under climate change condition, the increased uncertainty and extremity of already highly uncertain weather of tropical rainfed area will make rainfed agriculture more vulnerable. In most of the tropical rainfed agriculture region, rainfall is confined to short rainy season in form of limited high intensity rainfall events. Rainfed area accounts for about 80% of the world's agricultural land, contributing about 60% of global food production. About 95% of farm land in sub-Saharan Africa, 90% in Latin America, 60% in South Asia, 65% in East Asia, and 75% in West Asia and North Africa (WANA) (Rockström *et al.,* 2007). High spatial and temporal variability in rainfall is major constrain for improving production than total rainfall and it makes rainfed agriculture a risk prone venture.

Africa is one of the parts of the world most vulnerable to the impacts of climate change (IPCC 2014; Niang *et al.,* 2014). Temperature in Africa is projected to increase by 1.5°C by 2050 in comparison to 1951–1980 under low emission scenario (RCP 2.6) where as under high emission scenario (RCP 8.5) by 2100, temperature may reach 5°C above the 1951–1980 baseline. A dipole pattern of wetting in tropical East Africa and drying in southern Africa emerges in both seasons and in low as well as high emission scenarios, with both increases and decreases of 10–30%. Wetting of the Horn of Africa is also reflected in projected extreme precipitation events based upon the full CMIP5 model ensemble (Sillmann *et al.,* 2013). In south-western Africa, the projected shift toward more arid conditions due to a decline in rainfall is further likely to be exacerbated by temperature-driven increases in evapotranspiration. Rising demand from different sector and growing economy poses threat to water security in Africa. The high levels of dependence on precipitation and crop sensitivities to maximum temperatures during the growing season (Asseng *et al.,* 2011; Schlenker and Roberts, 2009) poses risks to the sector from climate change. ‘‘Worst-case’’ projections indicate losses of 27–32 % for maize, sorghum, millet and groundnut for a warming of about 2°C above pre-industrial levels by mid-century (Schlenker and Lobell, 2010). Climate Change Vulnerability Index for 2015 indicates seven of the ten countries most at risk from climate change are in Africa. The vulnerability to climate change is also high because of high dependence on rainfall and limited economic and industrial, capacity to provide resilience. Water conservation and improving water use productivity is one of the most advocated adaptations against climate change in Africa.

Under present affair, rainfed agriculture is grossly in sufficient to sustain the economic growth and food security. A major portion of rainfall received goes unproductive as less than 30% of rainfall, is used as productive green water flow (Rockström, 2003). This productive portion is further low to the tune of 15 to 30% sub-Saharan Africa, a water scarce region. The productive portion of rainfall is as low as 5% on degraded and low productivity land. About 10% of the rainfall is consumed as productive green water flow (transpiration) in arid areas with 90% flowing as non-productive evaporation flow (Oweis and Hachum, 2001). A major area (about 54%) in India faces high to extremely high water stress (World Resource institute). Even net water surplus areas witness water scarcity because of skewed distribution of rainfall – need conservation and management.

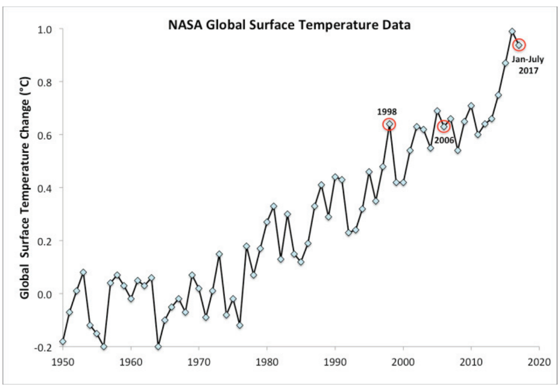


Table 1. Increasing temperature trend projections

Projected temperature under climate change (IPCC,AR-5)		
Temp Change	2046-2065	2081-2100
	Mean and *likely* **range**	Mean and *likely* **range**
RCP2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)
RCP4.5	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)
RCP6.0	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)
RCP8.5	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)

In order to meet the increased demand of water, it is essential to apply scientific principles for conservation and sustainable management of water resources. There is sufficient scope of improving productive part of rain water in rainfed agriculture through proper management particularly in Asia and Africa where lies large untapped potential in rainfed Agriculture. The fundamentals of rainfed agriculture management are to reduce rainfall induced risk and to enhance productive green water and blue-green water component.

Rainwater harvesting, creation of capacities of large water storage structure, artificial recharge to long-lasting ground water, in-situ water conservation by bunding, trenching, vegetative barriers, land configurations and enhancement of water use efficiency through improved irrigation method are keys to accomplish the goal of doubling farmers income. *In-situ* rainwater management strategies are often relatively cheap and should be optimized on any field before supply of water from external sources is considered.

The poor efficiency of surface water irrigation projects, which has been assessed to be about 30 to 40% at present, could be increased to 60% (at least) with proper maintenance and modernization of existing infrastructure and by adopting efficient management practices. Creation of additional capacity for water storage will also be highly useful for conserving precious water as about 70 to 80% of the surface runoff occurs during 3 to 4 months of the south-west monsoon season.

Water conservation and management is a must for driving farm production and income. Rain dependent area is rainfed area however for sake of management differentiation, it can broadly be into two (i) Dry land: precipitation < 750 mm, (ii) Rainfed area: precipitation < 750 mm. Though the management options are almost similar for dryland and rainfed areas, *in-situ*-harvesting is more feasible in rainfed areas where as *in-situ* water conservation is priority in dry land.

Water conservation strategy, Green vs Blue water

- *In-situ* conservation options for dry land-as well as rain fed areas - target is to concentrate runoff to cropped area, maximise infiltration.
  - ❖ Bunding: Contour, compartmental, graded, peripheral
  - ❖ Conservation furrow
  - ❖ Contour tillage
  - ❖ Furrow: Broad bed- furrow, ridge-furrow
  - ❖ Vegetative barrier
  - ❖ Mulching, reduced tillage
  - ❖ Conservation agriculture
  - ❖ Applying tank silt
  - ❖ Trenching: Staggered contour trenches, half moon
- *Decentralised water harvesting- more conversion to green water with purpose of* dry spell measure, protective irrigation, ground water recharge, off season irrigation
  - ❖ Renovating old water harvesting structures (tanks, ponds, reservoirs, channels, conveyances)
  - ❖ Sealing defunct wells or creation of ferro cement tank for water storage (pocket water)- may be connected to water grids in future

- ❖ Water harvesting though check dams, ponds, embankments
- ❖ Tapping surplus spring water
- ❖ Tapping base flow
- ❖ Roof top water harvesting

- o *DLTs for water conservation and recharge-support vegetation establishment*
- o *Wasteland development: compulsion and opportunity additional farm income*

In-situ **conservation options for dry land**

In-situ water conservation refers the conservation of water at the place where it falls where as *in-situ* water harvesting refers to harvesting water near the place of use as well as occurrence. The *in-situ* conservation is the first and foremost important component of water conservation in rainfed area. This is achieved by means of various soil surface manipulation including land configurations. Contour cultivation, contour bund, broadband furrow, tied ridges, blind furrows, micro catchments, trenching, stubble mulches and etc. are easy options for *in-situ* water conservation. In addition to support crops and ground water recharge, these conservation measures have important off site effect as it reduces runoff and soil loss considerably. The water conserved so as can be considered as green water as it is mostly used by crops Various land configuration measures tested mostly under dryland rainfed system (Table 2) was found to increase crop yield by 8 to 27%.

Table 2. Various land configuration for higher water use efficiency in dry land and rainfed area

Practices	Crop	Benefit	Ref
Different *in-situ* moisture conservation practices as compared to flat bed	Sorghum	Higher crop growth, yield attributes and yield	Robinson *et al*., 1986
Furrow opening in between the lines	Sorghum	Yield increase by 16%	Krishna and Gerik, 1988
Ridges and furrows as compared to flat bed	Sorghum	Increased grain yield by 25.6%	Patil and Sheelavantar, 2001
Broad furrow and ridge	Sorghum	Increase in grain yield by 27.2%	Itnal *et al*., 1994
Broad bed and furrow	Seed cotton	Higher yield during rain deficit year,	Koraddi *et al.*, 1993
Broad bed and furrow	Pearl millet	Maximum moisture use efficiency (8.38 kg ha^{-1} cm)	Kaushik and Lal, 1998
Bedding system with a furrow opened at the time of sowing at 1.5 or 3 m intervals	Finger millet	Yield increase by 8 to 10%.	Channappa, 1994
Paired row pigeon pea-finger millet intercrop with a furrow in between the pigeon pea rows	Pigeon pea-finger millet	Best in terms of water use efficiency and yield	AICRPDA

An additional income of rupees 1000 to 5000 (2010) were realized in the experiment conducted on broad bed furrow/ridge furrow, ridge and furrow planting of pigeon pea and upland rice, ridge and furrow across slope in Vertisol of Malwa region, Eastern Uttar Pradesh, Vindyan plateau and other areas (Table 3) under All India Coordinated Research Project on Dry land agriculture (AICRPDA).

Table 3. Effect of various land configurations for *in-situ* water conservation under AICRPDA.

Practice	Target Area	Benefit (Rs/ha)
Broad bed furrow/ ridge furrow planting	Malwa region Vertisols	3000-5000
Ridge and furrow planting of upland rice + pigeon pea	Eastern U.P/ Vindyan plateau	2500-3000
Ridge and furrow across slopes	Sandy soils of Haryana, Vertisols of Maharashtra, Eastern Rajasthan etc.	1000-1500

Conservation furrow (AICRPDA)

A conservation furrow opened at 45 DAS with *chip kunte* implement between two rows of pigeon pea in finger millet + pigeon pea (paired row 8:2) inter cropping system in southern dry zone of Karnataka was found to overcome the effect of dry spells during vegetative and reproductive stages. Additional finger millet grain equivalent yield of 1967 kg/ha was obtained in form of yield gain of finger millet as well as addition pegion pea yield. Increased rain water use efficiency by 2.25 kg/ha-mm, additional net returns of Rs.19545/ha compared to prevalent practice was realized. Conservation furrow is also used in Groundnut+ pigeon pea (8:2) intercropping in which conservation furrow is opened between two rows of pigeon pea at 35 days after sowing. Conservation furrow increased the crop yields of maize (22%), cotton (28%), and pigeon pea (25%) and produce least runoff, soil loss and higher water harvesting (up to 80%). Survival and growth of mango plants was observed to be 92% under V shaped catchment, 85% under crescent and saucer shaped bunds in rainfed central Gujarat region (ICAR-IISWC). This low cost innovative can be taken up in black soil region of Asia and Africa with annual rainfall of 500-800 mm

Conservation furrow in groundnut –pigeon pea intercropping pea.

Compartmental bunding (AICRPDA)

Making square compartments on field to retain rainwater and soil was found beneficial in terms of yield gain of 40, 35, 38 and 50 per cent in sorghum, sunflower, safflower and chickpea, respectively as compared to flat planting which resulted in additional income of Rs. 3500-6000/ha. Size of compartment varies from 3 x 3 m to 4.5 x 4.5 m depending on slope. Bunds are formed using bullock drawn bund former. This low cost technology of *in-situ* water conservation is recommended for Vijayapura, Bagalkot, Gadag, Koppal, Bellary, Part of Dharwad, Belgaum, Raichur and Davangere districts of medium to deep black soils of Northern dry zone of Karnataka. Higher moisture content in 45 - 60 cm soil profile at all growth stages and significantly higher seed yield in pigeon pea (1322 kg ha^{-1}) under broad bed and furrow (BBF) method compared to farmers' practice (1147 kg ha^{-1}) has been reported (Nadaf, 2013). Green gram sown on two meter wide broad bed and furrow (BBF) showed higher growth attributes, nodulation, yield attributes and yield compared to flatbed (FB) sowing (Shivakumar *et al.,* 2004). Tied ridges and compartmental bunding was found beneficial in conserving higher soil water as shown by higher biomass (7.02 and 6.62 t ha^{-1}) and nitrogen accumulation (101.79 and 92.68 kg ha^{-1}) in sunhemp compared to flatbed (Hiremath *et al.,* 2003). Mustard sowing on broad bed and furrow and ridge and furrow methods of land management during the first fortnight of October was found better for growth and yield of Indian mustard in Tirupati (Kumari and Rao, 2005). Higher grain yield (2350 kg ha^{-1}) of finger millet, and pigeon pea were observed on staggered moisture conservation furrow which resulted to B:C ratio of 2.38, as compared to farmers' practice (B:C ratio of 1.57) (Anon., 2011). Koppad and Manjunath (2006) found ridge and furrow and broad bed and furrow system most suitable for stevia and tulsi cultivation. Broad bed and furrow was the most suitable for kalmegh, while ridge and furrow was the most suitable for ashwagandha. Sowing of *rabi* sorghum on ridges and furrows and compartmental bunding resulted to 34.4 and 27.4 per cent higher grain yield, respectively, over the flat bed method of sowing (Kiran *et al.,* 2008)


Compartmental bunding

Mulching

Mulching is an important agronomic measure that not only dissipates the kinetic energy of the raindrops and prevents soil erosion but also facilitates infiltration and reduces runoff and evaporation losses (Krishnappa *et al.,* 1999). Spreading of porous mulching material like stone or plant residues on the soil surface during the rainy season increases water intake in the soil and reduces evaporation from the soil surface. Mulching improves physical, chemical and biological conditions of soil, thereby results in overall increase in soil moisture conservation and thus higher crop yield.

Stubble mulch farming tillage

Stubble mulch farming tillage techniques which comprises of one mouldboard plough + one cultivation along the contour, no planking to retain surface roughness, crop sowing along the contour and application of chopped pearl millet straw @ 2t ha^{-1} on the surface, in intercropping (cow pea+ castor) increased crop yield to the tune of 50 to 170 % as compared to conventional tillage (Kurothe *et al.,* 2014). The treatment also reduced runoff and soil loss by 60 and soil loss by 73% as compared to conventional up-down cultivation. The additional income generated was about rupees 8000 in 2012 per hectare. The technology is suitable for rain fed regions of central Gujarat, Maharashtra. SMFT was also found beneficial in pearl millet + pigeon pea intercropping.

Conservation agriculture under rainfed areas

Conservation agriculture based on concept of minimum disturbances (ZT, MT) to soil, crop residue cover and crop diversification encourages *in-situ* water conservation thus improves land productivity. Yield advantage may not be seen in short term but, gains in input use efficiency, by means reduced run off, soil loss, improvement in soil health results into higher economic benefits. In addition, it increases soil organic carbon thus has climate change mitigation potential and well as resilience.

Vetativer barrier filter

Grass vegetative strips for soil and water conservation

Vegetative filter strips on sloppy land, in between the crop has been found effective in water and soil conservation in addition to generate compensatory or additional income. For north western Himalaya region, slips of grass species of guinea, khus khus and bhabar along the contour line with paired rows in a staggered fashion at 1m vertical interval is planted on slope of 2 to 8%. The filter reduces runoff by 18-21% and soil loss by 23-68% (Ghosh *et al.,* 2011). The conserved soil and moisture resulted in maize and wheat yield increase by about 23-40% and 10-20% respectively. In addition to maize crop (grain + stalk), nearly 5.4 – 16.7 q ha^{-1} yr^{-1} dry grass yield is obtained as fodder from the barrier. The vegetative filter strip was also found effective on cropland in central Gujarat where vegetative filters strips of *Eulaliopsis binata* and *Dichanthium annulatum* grasses having 1-2 m width at spacing of 45 m reduced the runoff by 20 %, soil loss by 65%, and nutrient losses by 75 % from crop fields.

Contour trenches

Staggered contour trench one below another in alternate row is one of the economic option for water conservation on non arable land. It is mostly used as supportive water conservation measures for vegetation establishment mainly plantation. Runoff moderation and ground water recharge and sediment entrapment are other benefits of trenching. For ravine and marginal land of Rajasthan, Gujarat and Uttar Pradesh, rectangular staggered contour trench designed to tap 75% of runoff has been recommended. In order to facilitate easy designing with runoff and cost optimization a decision support system on trenching has been developed by ICAR-IISWC.

Conservation bench terraces (rain multipliers)

Tested long back, CBT can be used for water conservation and productive utilization in rainfed areas. In this method, a portion of sloppy (slope 2 – 6%) land surface is used as catchment which provides additional runoff to levelled terraces on which crops are grown. Initially meant for arid condition, this technology has been modified for rainfed areas. In area with annual rainfall > 1000 mm, even the sloppy catchment can be used for low water requiring crop like maize, vegetables and millets and bench terraces can be used for high water requiring crop. Additional run off is harvested in a pond and recycled to crops during dry spells. Maize and vegetable on the slope and paddy on the levelled terraces has been successfully grown in North West Himalayan region in which additional runoff was stored in lined pond and was recycled to crops. The CBT with suitable modification in land treatment and crops can be used if dry African region with precipitation of about 500 mm. A typical value of ratio between slopping land and terraces is 1:1 to 2:1, may be modified depending on rainfall and runoff generating characteristics.

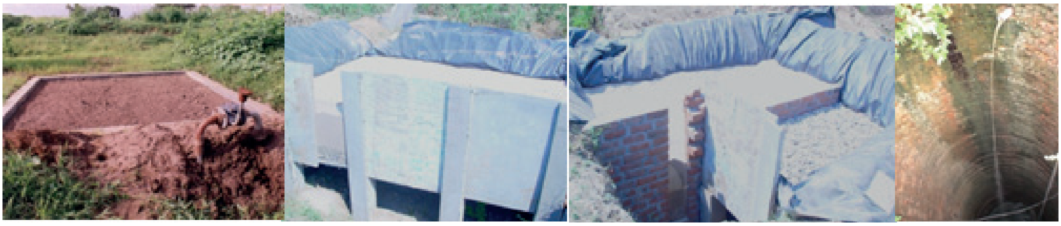
Bench terracing

Bench terracing is more of soil conservation measures on slopping land with deep soils. The main purpose is to reduce soil erosion and productive utilization of slopping land by means of water conservation. Bench terraces are made by cutting and filling to produces a series of steps called bench. Cultivation is done of benches. Inward slopping benches are recommended for greater stability. Periodic maintenance is required. Contour bunds and graded bund with provision of safe disposal of runoff have been extensively used as *in-situ* conservation measures and continue to be an economic option.

Any water conservation measure which delays and reduces the runoff flow contributes to ground water recharge. With increased urbanization, trafficking, compaction due to use of heavy machinery, the effective infiltration area and recharge is decreasing. Therefore, ground water is not only being depleted by excess withdrawal but also because reduced recharge. The quantity of recharge to an aquifer is considered equivalent to the safe yield. The rate of natural recharge is low means runoff is more subjected to surface flow and loss by evaporation. Artificial recharge generally reduces the time of evaporation.

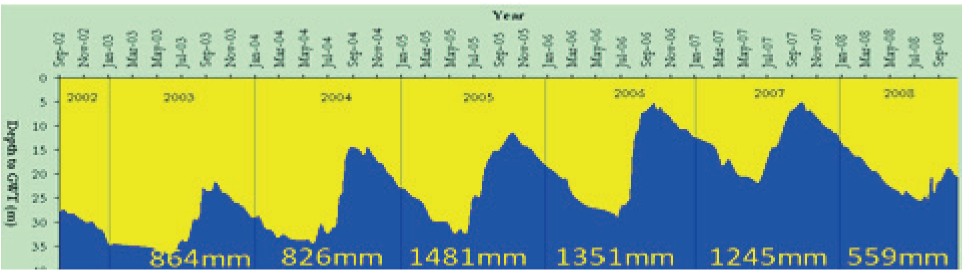
Direct well recharge technique

Direct well recharge reduces the time of evaporation which is major disadvantage in case of surface storage. A technique for direct well recharge using custom designed physical filter for runoff from low input management rainfed area has been developed by ICAR-IISWC. Gravity based sand + gravel filter with additional inverse component and shade-net on the top has been evaluated. Further for a runoff from flat land (slope<3%), an up-flow filter with higher hydraulic efficiency was also developed. For a runoff flow from high slope or channel, a two component filter has been developed in which first component is up-flow filter of gravel on a perforated slab and second component in gravity filter made of ungraded sand supported at the base by gravels and pebbles.



Different type of recharge filter (Gravity based filter, up-flow filter and two component filter) used for direct well recharge

The recharge filter along with other water conservation measures including bunding, trenching, and drainage line treatments resulted to groundwater augmentation and enhanced water availability for supplementary irrigation. Dead and defunct wells were primarily used for direct well recharge, non-functional wells were used. There was overall increase in ground water during post monsoon season. Higher ground water table was observed even during the rain deficit year (2008) despite of the higher withdrawal for longer period (Kurothe *et al.,* 2012).



Ground water table during different year

The higher water availability led to increase in irrigated area by 2.3 times, crop productivity by 17 to 200% and per hectare income by 1.49 times. Water access cost of recharged water is about Rs. 0.03/lit which includes cost of intervention as well. Though the benefit of using direct well recharge technology is well defined, beneficiaries are ill defined as the person using technology is not sure of total withdrawal of recharged water as it gets spread in the aquifer. Therefore the direct well recharge should be a community activity rather than individual. Recharge based upper ceiling on withdrawal at individual level seems logical and essential in long run.

Water harvesting and use strategies

In-situ water harvesting is an low external input option to increases the amount of water per unit cropping area, that can reduces impact of drought by using stored run-off beneficially which can makes farming possible on large part of the land if other conditions are suitable. Surface water has distinct advantage in terms of easy access for multiple uses including irrigation however; it is also subjected to loss by fast evaporation mainly in dry areas. Though it is difficult to figure out the clear advantage of *in-situ* water harvesting over ex-situ harvesting at large landscape scale due to climate and topographic complexities, decentralised approach of water harvesting infuses a sense of ownership at individual level which facilitate advance planning and therefore efficient use. For water harvesting, it is essential to create storage structure. Though not sufficient, a large number of storage structures have been created which is not in good shape due to poor maintenance. Therefore renovation and maintenance of old structures should be a priority. Thus water harvesting and use strategy in rainfed area includes strengthening of existing water storage structures like ponds, *nala* and check dam, construction of water harvesting check bunds, construction of roof top rain water harvesting structures, cconstruction of trenches for percolation of water, promotion of water conservation techniques like mulch, efficient management of harvested rain water through sprinkler and drip irrigation system, drip-fertigation system, adopting low cost lining material to check seepage, tapping spring water, tapping base flow by means of tanks and ponds. Innovations in structural materials, tools and machinery need to be tried for cost effectiveness and suitability

Tank silt- removal and application (ICAR-CRIDA)

There are about 140,000 tanks in states of Andhra Pradesh, Karnataka and Tamil Nadu and majority of them are silted up. Sediment from these tanks can ameliorate 5.6 million ha of dryland (@ 40 ha/tank) while creating an additional storage capacity of 1.4 BCM. Tank sediment was found rich in clay as it contained 58% of clay as against targeted soil having about 15% clay. The quantification of sediment application and benefits shows application of about 290 tonnes of sediment was sufficient to meet the N requirement of 120 Kg/ha in addition to increase clay by about 3-9%. The additional nutrients, textural modification (Table 4) and resulting favourable moisture regime resulted into higher water productivity of groundnut, cotton, *rabi* sorghum and maize (Table 5).

Table 4. Textural modification due to application of tank silt

S. No.	District name	Per cent							
		Sand	Silt	Clay	OC	Sand	Silt	Clay	OC
		Treated				Untreated			
1	Anantapur	76.9	4.1	19.0	0.38	78.2	5.4	16.5	0.30
2	Warangal	60.1	7.3	32.6	0.55	68.5	5.9	25.7	0.47
3	Solapur	46.5	12.5	40.9	0.38	53.6	14.8	31.5	0.30
4	Bhilwara	75.2	4.3	20.6	0.43	78.4	4.1	17.5	0.40

Table 5. Water productivity improvement due to tank sediment application

S. No.	District name	Crop	Water Productivity (Rs. ha^{-1} mm^{-1})			
			2008-09 (Year I)		2009-10 (Year II)	
			With	Without	With	Without
1	Anantapur	Groundnut	46.0	14.8	84.5	47.0
2	Warangal	Cotton	72.6	61.3	100.5	60.0
3	Solapur	Rabi sorghum	59.9	40.3	97.0	72.1
4	Bhilwara	Maize	54.4	44.0	55.4	41.3

The additional water stored in the capacity created due to sediment removal has multiple use primarily irrigation which adds up to productivity and income of the farmers.

Water harvesting in hills (ICAR-IISWC)

Small low cost water harvesting pond for gravity fed micro irrigation

In addition to surface runoff harvesting and direct rain harvesting, tapping surplus spring water is important water conservation measures in hilly areas. A good numbers of springs with large and small flow is available in north western as well as eastern Himalayan region. A model of stream or spring water harvesting and micro irrigation system for small farmers of middle Himalayan hilly region has been developed at ICAR-IISWC Dehradun. Water is diverted from perennial streams or springs stored in a low-cost pond and utilized through gravity-fed micro irrigation system to grow vegetable crops in hilly terraces. The approximate cost of silpaulin (200 GSM) lined pond of 10 cubic meter capacity pond including drip setup is Rs.16000 (2012). Drip irrigation system includes inline drip tape, mainline, screen Filter. This technology is recommended for terrace cultivation of high value vegetable crops for additional income.

Inter watershed water linkage

Pond for storing transferred water

Tapping surplus spring water resources in hilly areas has been found an effective and sustainable venture towards doubling farmers' income. Tapping surplus spring water can be considered as opportunity harvesting which is not available everywhere but there is large number of springs with surplus water or water with no on site use. Realising this precious resources getting wasted at one place where as other area need it badly, at innovative approach of harvesting these excess water and transporting to other watershed, which can be called inter watershed water transfer (Table 6) was attempted and met with great success in terms of increased irrigated area (2.86 times), vegetable cultivation area (2.86 times), annual family income (2.96 times), in-migration and positive attitude towards agriculture (Table 7). At one site a defunct tank was renovated and lined where as at another site a silpauline lined pond was constructed.

Table 6. Brief about the study area and major technological interventions

Villages (Dehradun district, Uttarakhand, N-W Himalayas)	Hattal	Sainj
No. of farm families targeted (beneficiaries)	130	35
Net cultivated area of targeted families (ha)	55	15
No. of small ponds (each 10 -20 cum) lined with silpaulin	32	27
Total length of HDPE pipe line (km)	8	5.6
Storage capacities of major tanks (cum)	480	200
Cost of interventions-pipe lines and WHS (Rs' lakhs)	12.44	8.66
Farmers' contribution	21 %	25 %

Table 7. Overall impact after three years

Parameter	Pre-project 2013	During 2016	Improvement (multiples)
Net irrigated area (ha)	10.5	30	2.86
No. of families practicing only agriculture	34	99	2.91
No. of families returned to Sainj village	-	8	In migration
Gross area under vegetables -tomato, cauliflower, peas, capsicum, cabbage, carrot, beans etc. (ha)	21	60	2.86
Total monetary output from vegetable cultivation in irrigated area (Rs' lakhs)	42.49	146.68	3.45
Av. annual family income from agriculture (Rs.)	28020	82950	2.96



Low cost Jhola kundi in Koraput district of Odhisha

Tapping base flow (ICAR-IISWC)

Harvesting subsurface water has added advantage of getting recouped periodically therefore even smaller structure can irrigate proportionally bigger area in comparison to surface water harvesting structure. There is scope of harvesting subsurface or base flow near foot hills or valley region. A low cost water harvesting technique in Eastern Ghats high land region of Odisha has been developed by ICAR-IISEC, RC-Koraput. A circular shallow well of depth 3 to 7 m and dia. 3 m is dug manually. Lining is recommended using locally available stone or by using pre fabricated perforated ring. A traditional water lifting device, *Tenda* or Krishak Bandhu pump (foot operated medium-lift double-stroke vertical reciprocating positive displacement treadle pump) is used. Diesel pump or solar pump can be used in bigger size Jhola kundi. Approximate cost of lined Jhola Kundi of depth 7 meter and dia. 3 meter is 1.1 lakhs, including the cost of 1.5 hp diesel pump. The payback period is 4-5 years and B: C ratio is 1.46 for calculated life span of 10 years. The actual life of lined Jhola Kundi is very likely to be much more than 10 years.

Surface runoff harvesting (ICAR-IISWC)


Embankment cum dugout pond

Water harvesting in embankment cum dugout pond for red soil of Bundelkhand region has been found beneficial as the stored water is used for life saving irrigation. The surface runoff generated from sloping lands during rainy season is harvested and stored into a dug out pond. The embankment cum dugout pond is constructed in the seasonal streams in red soils. With one supplemental irrigation, yield of soybean and toria increased by 40% and 180% respectively. Yield of mustard increased up to 400% with two supplemental irrigation. Overall cost benefit cost ratio of intervention was 2.3.


Plastic check dams under field evaluation (ICAR-IISWC)

Water conservation using check dam has become common practice in drainage line treatment. Realizing the scope of using new construction materials for cost cutting and easy working, ICAR-IISWC, has come up with plastic check dam. In this innovative check dam, headwall of otherwise brick masonry is replaced with Polypropylene (PP)/PVC/ HDPE/FRP. PP was found most cost effective (Table. 8). The different thickness of sheet is under field evaluation for longevity. Easy working and transportation to difficult sites are added advantage.

Table 8. Cost effective and innovative plastic check dams

S. No.	Type of material	Unit rate, Rs	Amount, Rs (2014)	
			10 mm	15mm
1	PP	135/ mm/Sqm	14661	20742
2	PVC	206 mm/Sqm	21006	30259
3	HDPE	153 mm/Sqm	16248	23121
4	FRP	352 mm/Sqm	34225	50088
5	Brick masonry	5500 m^3	49050	

Water harvesting in Large ponds (ICAR-IISWC)

Though creating a large pond (size >0.5 ha) is difficult in hilly area mainly because of topographical constrain, but there are places of opportunity need to be utilized. One such large depression were made functional pond by sediment removal, shaping and by providing pipelines for irrigation (Table 10). Catchment area improvement was also part of the intervention. This technology is recommended from Shiwalik region of Himachal Pradesh, Haryana and Punjab.

Jalkund

Direct rainfall collection in water catches ponds or has been proved beneficial on high rainfall north east Himalayan region. The technology called *Jalkund* comprises of pond of 10 to 50 cubic meters capacity, bigger size is also being evaluated. The water is used for irrigating high value vegetables and other crops. Harvested water can safely be utilized for animal husbandry activities, piggery, poultry and duckery. With multiple filling a 30 cubic meter Jalkund can be used to irrigate 0.2 to 0.6 ha area. Jalkund is being promoted under NICRA, TSP, and Meragaon-Mera Gaurav programme by the ICAR Research Complex for NE region.

The nomenclature has also been extended to an extended area rain collection lined pit of capacity 3-5 cubic meter in semiarid area. This type of Jalkund is primarily used for irrigating orchard/plantation in semiarid area. The top of lined pit is covered by locally available thatch/straw and bamboo splits in which a small opening is made for lifting water using bucket. Almost vertical cut is made for digging pit, depth is limited to 1-1.5 meter, LDPE is used for lining. This harvested rain is so efficiently stored with proper lining and cover that it qualifies to be called pocket water (analogous to pocket Money) for which use can be planned effectively.

The innovation in other fields needs to be looked for making innovative technology in water conservation. With advent of efficient drilling machine (used for metro pillar foundation), underground ferro-cement lined tank (like well) may be tested as an alternate of farm pond. Advantage of more depth, less area occupied, no seepage and reduced evaporation loss (if covered) may overcome the cost disadvantage. Further these tank can be connected to water grid system if happens in future.

Watershed management

Watershed management includes a combination of interventions for effective conservation of soil and water for sustainable production and reduction of environmental hazards. Management of land and vegetation using recourse conservation technologies is done to conserve the soil and water for immediate and long term benefits. Watershed programmes in India are about 5 decades old and started with the establishment of a chain of Soil Conservation Research, Demonstration, and Training Centres by Ministry of Agriculture during first five year plan. A centrally sponsored scheme of soil conservation in the catchments of River Valley Projects (RVP) was launched in 1961-62 by Ministry of Agriculture in 27 catchments to prevent siltation in major reservoirs of the country (Table 9). The real breakthrough occurred in 1974 when watershed technologies were demonstrated under natural field settings following community driven approach through 4 model Operational Research Projects (ORPs) in different regions including the world famous Sukhomajri model in Haryana. With the tremendous success achieved in these projects, CSWCRTI, Dehradun in association with Central Research Institute for Dryland Agriculture, Hyderabad developed 47 model watersheds in the country in 1983. Since then, many successful watershed development projects have been demonstrated by the Institute in different regions of the country with funding from Ministry of Rural Development and Ministry of Agriculture and Farmers Welfare.

Table 9. Watershed programme in India

Programme	Initiation/induction in watershed mode	Ministry
Drought Prone Area Programme (DPAP)	1973-74	Ministry of Rural Development
Desert Development Programme (DDP)	1977-78 adopted watershed approach since 1987	Ministry of Rural Development
National Watershed Development Programme for Rainfed Areas (NWDPRA)	1991	Ministry of Agriculture
Integrated Wastelands Development Project	1995	Ministry of Rural Development
River Valley Projects	1961-61 comes under Common Guidelines for Watershed Development Projects in 2008	Ministry of Agriculture
Integrated Watershed Management programme (combining DDP, DPAP, IWDP)	2009	Ministry of Rural Development

Comprehensive assessment of watersheds in India (636 micro watersheds) reveals multiple benefits in terms of augmenting income, increasing crop yields, increasing cropping intensity (35.5%), reducing runoff (45%) and soil loss (1.1 t/ha/year), augmenting groundwater, building social capital and reducing poverty (ICAR-IISWC). By implementing resources conservation technologies with watershed concepts in six IWDP funded watersheds by IISWC

- Overall Crop Productivity Index (CPI) increased by 12 to 45% (avg 28%)
- Crop Diversification Index (CDI) increased by 6 to 79% (avg 22%) Cultivated Land Utilization Index (CLUI) improved by 2 to 81% (avg 27%).
- Inducted Watershed Eco-index (IWEI) improved by 12%, additional watershed area was rehabilitated and brought under green cover.
- Creation of water storage capacity of 12 to 158 ha-m and
- Increased irrigated area by 65 to 585%,
- Reduced runoff by 9 to 24% and
- Increased groundwater table by 1 to 2 m in the watersheds
- Rural employment of 151 mandays/ha, on an average.

In terms of economic efficiency, watersheds generated an average

- Benefit-cost ratio (B:C) of 2
- Failure - 0.6 per cent of watersheds B:C ratio <1
- Mean internal rate of return (IRR): 27.4 per cent.
- 32 per cent of watersheds: BCR of > 2
- 27 per cent of watersheds: IRR > 30 %,

The benefit realized is evidence to believe that watershed programme has been one of the most successful lands based rural development programme. With suitable modification, watershed programme has potential to improve farmer's affair in Africa through water conservation and efficient management.

Water management innovations in rainfed areas

Water conservation is important for rainfed area but efficient water management is more important because a sizeable portion of water can be spared to bring more rain fed area under irrigation.

Need for irrigation in rainfed areas

Complete dependence on rainfall renders cultivation in un-irrigated regions uncertain and at a high risk. Assured or protective irrigation encourages farmers to invest more in farming, improved technology and modern inputs leading to productivity enhancement and increased farm income.

Improving irrigation efficiency is must for improving productivity and bringing more area to irrigation. The wild approach of using surface irrigation is considered grossly inefficient in which more water is used to wet soil than plant use. Instead of irrigating soil, higher portion should be utilized by plant. Options are available in terms of pressurized irrigation (drip, sprinkler), protected cultivation. Fertigation is another domain in which, use efficiency of both water and nutrients is improved.

A major portion of black soil in India is not being cultivated during *kharif* season because of poor workability and seasonal water logging. The water management in rain fed area must include drainage so that more area can be brought to cultivation. Preference should be given to such options which facilitate both water conservation as well as drainage.

Annual participation in Africa ranges from 50 mm to 4000 mm per annum, however, a large part of agricultural land in Africa fall under 500 to 1500 mm annual rainfall therefore are suitable for effective watershed management and water harvesting. Having similar range of rainfall and skewed distribution, the experience in *in-situ* water conservation, water harvesting and watershed management can be extended to African farmers in coping low water productivity and climate uncertainty.

Summary

- *In-situ* conservation by means of land configuration, broad-bed furrow, ridge furrow, tied ridges, trenching, contour and graded bunding, V- shaped catchment are good practices to improve farm productivity and farmer's income in rainfed area in Asia and Africa.
- Decentralized water conservation (green and blue) including harvesting water in embankment and dugout pond, use of low cost plastic check dam, tapping excess spring flow, inter watershed linking, tapping base flow by innovative approach are important towards improving rain fed productivity.
- Renovating old water harvesting structure should be priority as silt removal from tank and application in agricultural field has double benefit in terms of improved water storage capacity, improved soil health and higher income.
- Watershed management comprising various water conservation and management intervention in scientific approach, along with promoting social equity has been proved one of the most successful land management options in India, expertise available may be extended to African countries. However, a continuous research is required to utilize contemporary development in tools and technologies to make the programme more inclusive.
- A considerable portion of rainfed area mainly black soils in India and Africa also suffer from seasonal water logging therefore drainage must be part of rainfed water management strategy.
- Interlinking of river, coupled with national water grid, taluka level sub grid and farm level pocket water-tank/well capable of utilizing runoff as well as grid water for protective irrigation is the key of evergreen revolution in Asia as well as in Africa.

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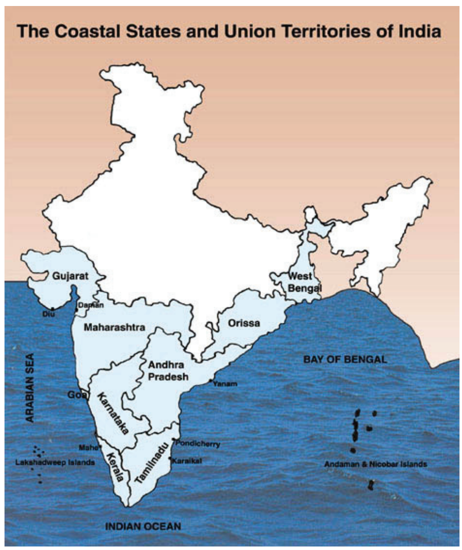
Issues and Strategies for Enhancing Agricultural Productivity in Coastal Lowlands

S.K. Ambast
Director
ICAR-Indian Institute of Water Management, Bhubaneswar – 751023
Email: skambast65@gmail.com

Coastal ecosystem includes estuaries, coastal waters and lands located at the lower end of drainage basins, where streams and river systems meet the sea and are mixed by tides. Functionally, it is broad interface between land and water where production, consumption, recreation and exchange processes occur at high rates of intensity. Ecologically, these areas are dynamic, biological, hydraulic, geological and chemical activities often with considerable but always in limited capacity for supporting various forms of human use. However, such areas are fragile and vulnerable which both nature and man have and will muscle in both constructive and destructive ways. The total global coastlines exceed 1.6 million kilometers and coastal ecosystems occur in 123 countries around the world (Burke et al., 2001). The coastline of India is about 7,516 km, of which the mainland accounts for 5,422 km and Islands extends for 2094 km (Table 1) and has a continental shelf area of 468,000 sq km, spread across 9 coastal States and 3 Union Territories (Fig.1).

Table 1. Distribution of coastline in India

State/Union Territories	Coastal Length (km)
West Bengal	157.5
Orissa	476.4
Andhra Pradesh	973.7
Tamil Nadu	906.9
Kerala	569.7
Karnataka	280.0
Goa	151.0
Maharashtra	652.6
Gujarat	1214.7
Pondicherry	30.6
Daman and Diu	9.5
Andaman and Nicobar	1962.0
Lakshadweep	132.0
Total	7516.6



Agriculture in the coastal ecosystem is predominantly rainfed in nature, characterized by excess water during the rainy season followed by acute water scarcity coupled with soil/ water salinity in the post-monsoon period, poses severe threat to improved agricultural production as well as productivity. In general, coastal lands are mono-cropped with low productive rice paddies along with fresh/brackish water aquaculture, unsystematic horticultural crops and limited livestock. On the other hand, coastal regions are seen as the potential areas for bridging the expected shortages in the national food production in future due to high rainfall (Fig.2) and low agricultural productivity (Fig.3). The scope of post harvest technology and value addition is immense. Integrated natural resource management is good for planning strategy, watershed management is good for program implementation and farming system approach is more suiting to beneficiaries. However, looking to the small land holdings in coastal ecosystem, farming system approach seems to be more appropriate. As region faces the severe threat in the form of sea level rise, extreme weather events, storm/cyclonic disasters and coastal erosion in climate change scenario, it calls for development of integrated strategies based on natural resource management for enhancing agricultural productivity to ensure livelihood suiting to different coastal sub-systems.

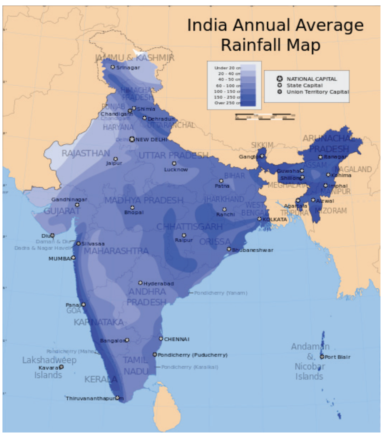


Fig.2. Mean rainfall in India

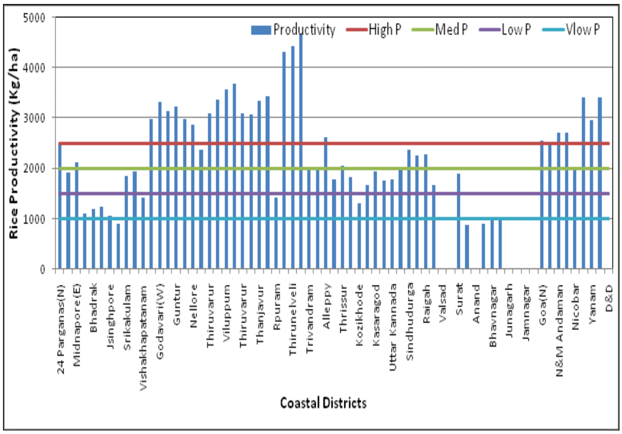


Fig.3. Rice productivity in coastal districts

Coastal Ecosystems

The National Bureau of soil Survey & Land Use Planning of India (Sehgal et al., 1992) has brought out a 21 zone agro-ecological regional map of the country, essentially based on physiography, soils, bio-climatic types, and growing period which influences the supply of water for plant growth. The zones coming under coastal ecosystems are:

(a) Eastern Coastal Plain, Hot sub-humid Ecoregion with Alluvium, derived Soils: It covers the eastern coastal plain extending from Cauvery Delta to Gangetic Delta and occupies 2.5% of the land area. It has hot summers and mild winters, with an annual rainfall of 1200 to 1600 mm. The growing period ranges from 150-210 days. The soils are mainly clayey with slight acidity. Rainfed and irrigated rice farming are practiced. Imperfect drainage and salinity are the major constraints.

(b) Western Ghats and Coastal Plains, Hot Humid-Parhumid Ecoregion with Red, Laterite and Alluvium-derived Soils: It constitutes Western coastal plains of Maharashtra, Karnataka, and Kerala States covering 3% of the land area. It has hot summers, with rainfall exceeding 2000 mm. The growing period is more than 270 days. It has red, lateritic and alluvial soils. Waterlogging and severe erosion are the major problems. It has high potential for export oriented plantation crops.

Climate and soils

The climate of most of the coastal sub-regions in India falls under the hot and humid or sub-humid condition with limited variations (except the North Gujarat coast which is semi-arid). Almost the entire coastal area in the country, excluding the north Gujarat coast, receives a normal annual rainfall in excess of 1000 mm with the west cost receiving more than 2500 mm per year and 80% of it occurring during June to September in Gujarat, Maharashtra and Karnataka. In West Bengal and Orissa some amount of rainfall is also received during May and October as well. Tamil Nadu receives about 70% of rainfall during October and November. Thus, most of the coastal areas have surplus rainfall either during June-September or October-December. In the coastal areas, very heavy rainfall events of 200 to 400 mm in 24 hours are frequent thereby causing surface waterlogging, flash floods and damage to crops and property. The average maximum temperatures are in the range of 25 to 30^0C whereas the average minimum temperatures seldom fall below 20^0C during the winter months of December to February. The annual evaporation ranges from 1350 to 2150 mm in West Bengal and in Gujarat, respectively. The high evaporation causes salinization of surface soil especially in dry seasons in the presence of high and poor quality groundwater. Soils in coastal areas are in general deep to very deep, imperfectly to poorly drained, sand to fine loamy to fine in texture. The sandy shores are covered partly with water during high tides and stormy periods. The soils are calcareous, slightly to moderately saline and alkaline. Heavy exploitation of groundwater in many coastal areas has resulted in seawater intrusion and development of high soil salinity.

Production system constraints

The agriculture in the coastal ecosystem is predominantly rainfed in nature and is characterized by excess water during the rainy season followed by acute water scarcity in the post-monsoon period and this poses a severe threat to improved agricultural production as well as productivity of the regions. Management of rainwater is, therefore, crucial particularly with regard to the smallholdings in the costal ecosystem. Apart from erratic rainfall pattern, the poor and inefficient water management practices result in about 70% loss of the rainwater, mostly as surface runoff to the seas, thereby reducing the per capita availability of fresh water to the coastal people. Kerala state presents a typical example where despite more than 3000 mm annual rainfall, the per capita effective rainwater availability is less than even some dry parts of Rajasthan mainly due to heavy surface runoff loss because of steeply sloping topography, excessive deforestation and road construction. Moreover, the growing competitive demand for good quality water from industry, power and household sectors is further compounding the water crisis. The excess runoff results in eroding the top fertile soils of the region and also leads to poor ground water recharge due to lesser ponding time. The indiscriminate and excessive withdrawal of ground water causes lowering of water table and also ingress of seawater, which in turn, leads to acute salinization of land and water. The poor drainage is another key factor limiting the agricultural production in the coastal region. The excess rainwater available during the monsoon period needs to be conserved through reduced runoff and storage in ponds so as to reuse it as life saving irrigations to the crops during the lean periods. However, it is important to optimize the land and water allocation for maximizing the net profits. The problems related to productivity in coastal areas may be summarized as:

1. Inundation of agricultural lands by tidal water and seawater ingress in aquifers
2. Impeded surface and subsurface drainage conditions
3. High soil salinity due to shallow saline groundwater in winter/summer months
4. High and erratic rainfall causing lack of irrigation water in dry periods and second crop
5. Lack of irrigation infrastructure
6. Unscientific integrated farming system
7. Conflict between farmers practicing agriculture and brackish water aquaculture
8. Sea level rise, extreme weather events and cyclones/storms in climate change scenario

Options of improving agricultural productivity

Integrated natural resource management, watershed management or farming system approach are the terms often used synonymously though their dimension of area vary from basin to farm scale (Fig.4). The integrated natural resource management is good for planning strategy, watershed management is good for program implementation and farming system approach is more suiting to beneficiaries. In all these approaches, rainwater management forms the basis of improvement. However, looking to the small land holdings in coastal ecosystem, farming system approach seems to be more appropriate. It is an integrated approach on rainwater management dealing with on-farm storage of excess rainwater during monsoon season and recycling the same for irrigation of crops during deficit periods in dry season with the objective to introduce multi-cropping in the otherwise predominantly mono-cropped areas.

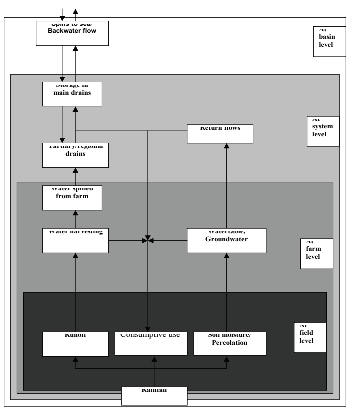


Fig.4. A framework of hydrological processes at different scales in coastal region

Agricultural land drainage

Most of the coastal low-lying areas are frequently inundated due to ingress of seawater through tidal estuaries. These estuaries are slowly silting up due to high silt load carried along with the river flows causing congested drainage system and thus flooding of agricultural fields. It has been suggested that earthen embankments, preferable brick pitched, having side slope of 3:1 on the river side and 2:1 on the country side, with 1 m free board above the high tidal level are appropriate for protection against flooding (Rao, 1981). In order to facilitate quick removal of excess rainwater and to stop the ingress of sea water in low-lying areas, construction of peripheral embankments with provision of one way sluice gates and construction of drainage network will be necessary. In general, a three-tier system of surface drainage is recommended for effective and economic view (Gupta et al., 2006):

1. Rainwater is allowed to accumulate and remain in the fields till such time and extent as will not be harmful to crop.
2. Excess water from the fields is led to the dugout ponds of sufficient capacity. The stored water can be utilized subsequently during dry spells or for irrigating winter season crops.
3. Rainwater in excess of these two components of storage is taken out of the area to the creeks/sea through appropriately located one-way sluice gates/structures.

Rainwater management

A comprehensive work on rainwater management in Sundarbans delta, West Bengal is presented by Ambast et al. (1998). Based on probability analyses of historical rainfall and evaporation data, following significant achievements have been emerged out of the study:

(i) With an average annual rainfall of 1768 mm and evaporation of 1581 mm, July and August are the wet months having probability of severe crop damage due to waterlogging. On an average, 5-weeks drought (3-week continuous at ripening) may occur during kharif season.

(ii) Based on probable R-PET data, rice-transplanting schedule was developed for reducing climatic hazard in different land topo-sequences. Further, a crop calendar of optimal farming operations is developed for minimizing production losses due to uncertain weather.

(iii) Water balance analysis show considerable scope of rainwater harvesting in on-farm reservoir (OFR). It was recommended to convert 20% of the farm area into OFR. The procedure may be used for optimal design of OFR in different agro-ecological conditions.

(iv) Simulation of surface drainage improvement with and without OFR indicated surface drainage improvement up to 75% in low-lying rice areas of East Mograhat Drainage Basin. It provides scope for cultivation of HYV of rice in rainfed humid rice lowlands.

(v) It is estimated that 1-supplemental irrigation might be required at grain formation stage in two out of ten years that will stabilize rice production in kharif season.

(vi) Linear programming model is used for optimal land and water allocation in dry season for various land and water constraints for maximizing profits. Optimal allocation indicated BC ratio of 2:1 (excl income from fishery & horticulture), thus justified the investment in OFR.

Further, user-friendly computer software RAINSIM (Rainwater Simulation Modelling) is developed (Fig.5).

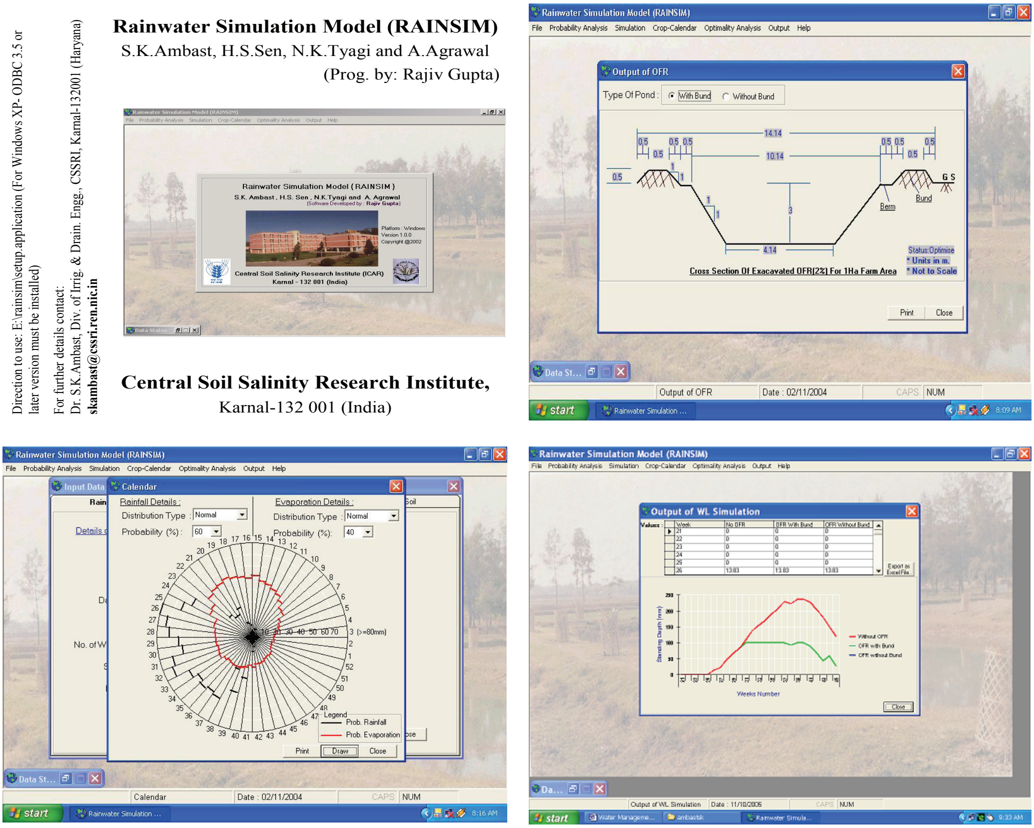


Fig.5. (a) RAINSIM software (b) OFR design (c) crop calendar and (d) simulation of drainage improvement

Precision farming and improved irrigation methods

Precision farming or site-specific farming is an emerging technology that allows farmers to have most efficient use of inputs and agronomic practices. It has the potential not only to reduced cost of cultivation through more efficient and effective application of crop inputs but also protects the fragile environment. Precision farming is very essential because inputs in agriculture such as fertilizers and pesticides and based on non-renewable source of energy. A careful water balance analysis of annual precipitation and potential evapotranspiration is essential to determine the water surplus/deficit periods beforehand, so that all the agricultural operations can be adjusted accordingly. This will help to save the crops from water stress (excess/deficit) during its critical growth stages and also help the farmers in the decision-making regarding crop choice as well as its acreage depending upon the water availability. The concept of harvesting excess rainwater in OFR may be effectively utilized for growing pulses, oilseeds, tuber crops, vegetables, spices, etc. after kharif rice.

Water conserved in limited quantity should be judiciously used for irrigation. Limited information are available on irrigation methods for the coastal ecosystems, where, in general, the soils are to a large extent saline and medium to heavy texture in nature. Micro-irrigation, especially in the form of drip, should be a potential irrigation method for coastal environment. Drip irrigation system can prove beneficial for the coastal region particularly to irrigate the high value crops such as plantation crops of coconut, areca nut, oil palm, cashew and cocoa, spices viz., black peeper, cardamom, ginger, turmeric, coriander, cumin, etc. The controlled use of water and fertilizer directly in the root zone through drip irrigation not only increases the input use efficiencies but also reduces possible negative interactions in the soil profile. Besides, this system provides scope of using poor quality water in conjunction with fresh water for irrigation. Another improved technology to utilize the surface water is life-saving irrigation by digging doruvus which is a conical pit dug to collect seeped in water. In this method, suitable particularly for sandy loam soil fresh water floating over saline groundwater may be skimmed horizontally through tile drains at the rate of 18 lps, which would be sufficient for operating 6 sprinklers continuously. The technology has been tested in Andhra Pradesh.

Spatial techniques for of natural resource management

Space programmes, all over the world, have unique dimension to use space technology for sustainable development of natural resources. Applications of remote sensing in agriculture begin with inventory of soil and surface water resources, today its applications witnessed a phase transition from resource mapping to decision-making due to its enormously improved capability to monitor agricultural and hydrological conditions of the land surface.

Monitoring land drainage schemes: A number of surface drainage projects are in operation in coastal areas to ease the surface waterlogging. The performance monitoring of these large drainage projects through field observations and construction of water level hydrographs is quite difficult. Moreover, very limited attempts have been made to develop the criteria to evaluate the surface drainage systems (Ambast, 1996). Absence of total vegetation on severely waterlogged or salt-affected soil surface makes it possible to detect waterlogged and saline surfaces directly from the remote sensing, whereas it is difficult to identify slightly or moderately affected waterlogged and salt-affected cropped land directly. But such waterlogged and saline cropped land have very distinct reflectance characteristics due to patchy crop growth and can be identified indirectly with low albedo-low NDVI and high albedo-low NDVI, respectively (Ambast and Tyagi, 2002; Fig.6). The economic analysis for Bhalaut branch canal indicated an average loss of 18% of the potential due to waterlogging and soil salinity in the command. Similar technique may be employed in coastal saline lands to monitor waterlogged and saline lands.

Estimation of crop yield: The ultimate aim of efficient drainage system is to enhance the crop and water productivity uniformly in the drainage basin. Field observed regression model between NDVI and crop yields has been extrapolated for crop yield estimation of large areas using spatial technique in Sone Low Level Canal system for wheat crop and applied on remotely sensed data (Ambast et al., 2002). The estimated crop yield is shown in Fig.7. Similar technique may be employed in coastal drainage basins to estimate crops yields to monitor performance of drainage systems.

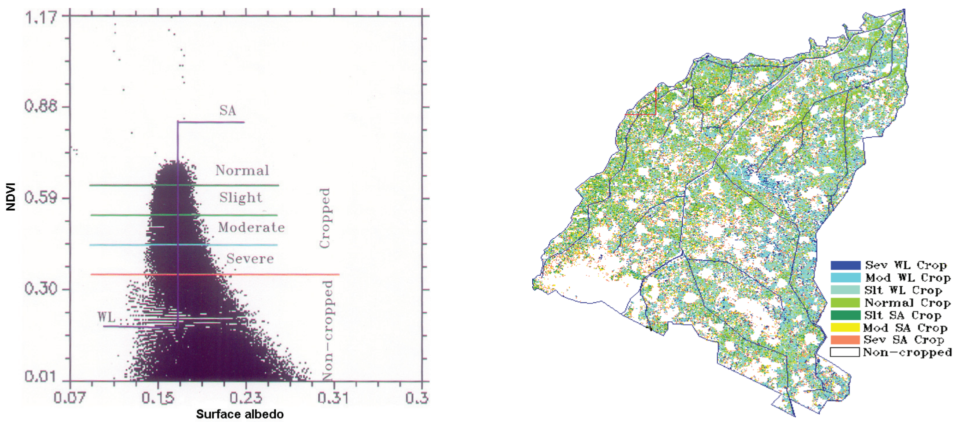


Fig.6. (a) Concept and (b) application of delineation of waterlogged and salt-affected land

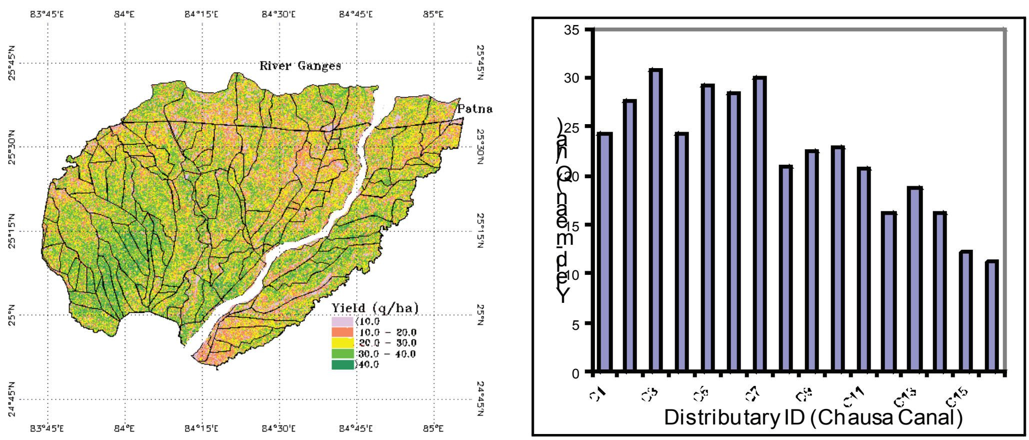


Fig.7. (a) Wheat yield image and (b) mean crop yield

Land shaping interventions

In humid coastal areas, surface waterlogging during kharif and non-availability of water during rabi is major problem. Land shaping is the articulation of land arrangement so as to overcome hydrologic problems in agricultural area for potential crop cultivation. Some of the land shaping techniques followed in the A&N Islands and Sundarbans delta are pond based integrated farming, broad bed and furrow, rice-cum-fish, three tier land management and ridge and furrow systems.

Pond based integrated farming system (IFS): Farm ponds, as one of the suitable options of land shaping, form the centre of integrated farming system (Fig.8). It may store in-situ rainfall or harvest surface runoff from surrounding areas depending upon the available rainfall in a region. In high rainfall areas, like A&N Islands where average annual rainfall is about 3100 mm, even in-situ rainwater storage in farm pond serves the purpose. However, in areas where surface runoff is the main source of water, the contributing drainage area or watershed should be large enough to maintain desired water level in the farm pond. The requirement of expensive overflow structures may be avoided by optimising the catchment vs. storage area. The required catchment area depends on soil type, land use and land slope. The steps involved in planning, designing and constructing a farm pond includes (i) rainwater availability, (ii) crop water requirements, (iii) design dimension of farm pond, (iv) location of the farm pond and (v) lining requirement for seepage control. However, optimal land and water allocation among several components of integrated farming system is the most important for maximizing the farm profit.

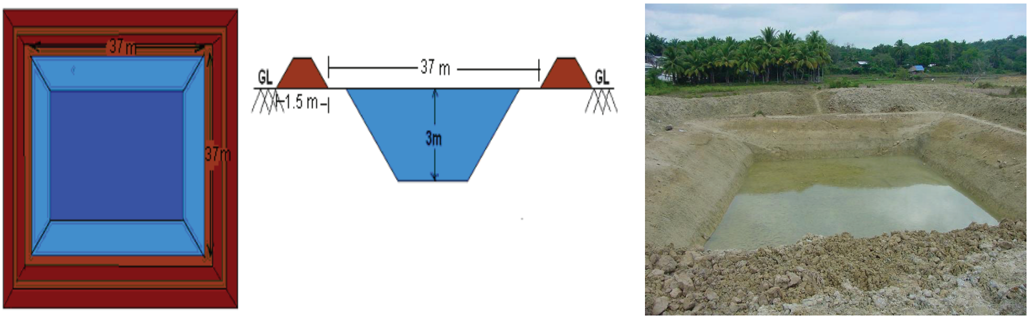


Fig.8. Plan and side view of the suggested farm pond for 1ha land

Broad bed and furrow system (BBF): It involves making of broad beds and furrows alternatively in rice fields. The ideal location is the flat low lying area, where floodwater stagnates and only rice crop can be grown. Broad beds are made in the shape of inverted trapezium by digging soil from either side of the broad bed and putting it in the bed area by cut and fills method (Ravisankar et al., 2008). The excavated depressed area is used for rice cultivation and the raised broad bed area which is above the water level of the paddy fields are used for cultivating any seasonal vegetable or fodder crop during monsoon period. The beds of 4-5 m wide and furrows of 5-6 m wide were found suitable for this system of cultivation. The BBF system is shown in Fig.9. Planting two rows of hybrid Napier on both sides of the bed stabilizes the broad beds. At the end of the furrow on descending side, a fish shelter or pond is to be excavated. In this pond, the fish farming can be along with rice. This is added to the profit as well as livelihood of the farmer. From the bund of the furrow, two PVC pipes of 2 m length may be provided for draining out excess water. The system increases the cropping intensity from the present level of 100 in the rice to 300 in the beds and 200 in the furrows of the broad bed-furrow system. The initial cost of about Rs. 100,000/ha incurred on land manipulation is easily returned back from vegetables produced in one season. The technology helps in crop diversification by replacing 40% of the rice area with vegetables and fodder. This technology can also be extended to similar coastal plain areas in other parts of the country.

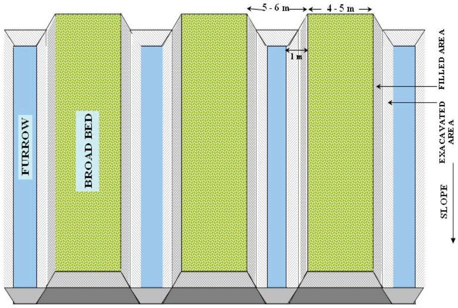


Fig.9. A typical sketch and a view of broad bed and furrow system

Paddy cum fish system (P-F System): Integrating aquaculture with agriculture assures higher productivity and year round employment opportunities for farmers. The plots utilised for rice cum fish system (Fig.10) is mainly based on organic fertilisation with a varieties of animals excreta such as poultry dropping, pig excreta, cow dung and wastes of plants such as rice husks and ashes from household burnt and remains of burnt straws after the harvest is over. Compost fertiliser like decomposed straws, weeds and stalks. The rice field can be utilized for fish culture in the following two ways. Fishes can be reared from the month of May to September when the paddy crops grow in the field. The fish culture can also be taken up from the month of November to February after harvesting of paddy crops is completed and transplantation for the next season begins. The culture of fishes in paddy fields, which remain flooded even after the paddy is harvested, may also serves as an occupation for the unemployed youths. Paddy field is suitable for fish culture because of having strong bund in order to prevent leakage of water, to retain up to desired depth and also to prevent the escape of cultivated fishes during floods. The bunds built strong enough to make up the height due to geographical and topographic location of the paddy field. Bamboo mating was done at the base of the bunds for its support.

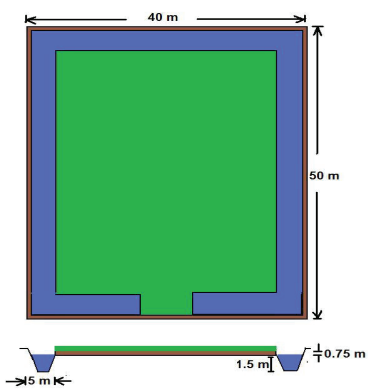


Fig.10. A layouts and a typical view of paddy-fish system

Ridge and furrow system (R-F System): In low lying areas, the paddy land is converted into ridges and furrows (Fig.11). This system is semi-permanent type, which could be lasted for 3-5 years. Regular maintenance is required for proper shaping of ridges. The paddy land is converted into ridges by cutting the soil and making the ridge. The width of the ridge and furrows are 1.0-1.5 m and height of up to 0.5 m. The earth cutting and filling operation could be accomplished manually by spade in the summer. At the time of filling the soil should be compacted. It will prevent the soil erosion. The ridges are used for plating of coconut, arecanut and banana. If possible vegetable crops could also be grown on the ridges.

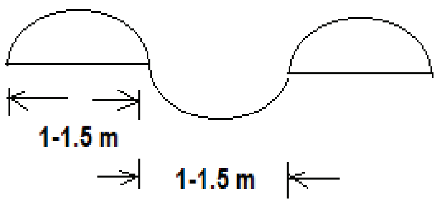


Fig.11. A layout and a view of ridge and furrow system

Three tier land farming system (TTLF): In this, one third part of the land is dugged to a depth of 2 m or more depending up on the site specific condition and the dugged soil can be spread to the other extreme of the field so as to raise this part by at least 1 m whereas some soil can be used for making bunds around the pond (Fig.12). The middle part of the field remains at the original ground level. In the raised part, vegetables can be grown whereas in the middle part rice is grown. The rainwater can be harvested in the dugged part and fish can be integrated. This enhances the net return of the farms.

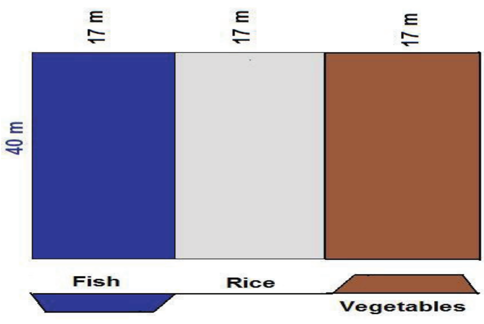


Fig.12. A typical sketch and view of the 3-tier land farming system

Horticulture/Livestock Based Integrated Farming System

In coastal areas, coconut is intercropped with spices i.e. black pepper, clove, cinnamon nutmeg and ginger. Although the selection of main crop and the intercrop may vary from one place to another place, broadly the farmers can select coconut with clove, cinnamon, black pepper, banana, papaya and their combination. The requirement of seedlings for various combinations of planting is given in Table 2. Production from coconut based farming system is very high but complex. It is possible that a farmer may earn income from the second year onwards through intercrop and after 4-5 years from main crop, though it may take up to 10 years for the entire plantation giving production. The expected yield per unit area at full production is given in Table 3.

Table 2. Requirement of seedlings for different combinations of coconut based system

Crop	No. of seedlings (Nos/ha)	Remarks
Coconut (7.5 m x 7.5 m)	178	Main crop
Clove	169	In between 4 coconut trees
Cinnamon	169	In between coconut rows
Banana	507	In between coconut rows
Black pepper	178	Over coconut trees
Pineapple	-	Location specific

Table 3. Yield and gross return from coconut based farming

Crops	Yield (kg/ha)	Rate/unit (Rs)	Gross return (Rs)
Coconut	8900 nuts	3	27000
Clove	34	300	10000
Black pepper	267	60	16000
Banana	5070	10	50700
Cinnamon	9.5	110	930

Nutrient Management: Young palms respond well to the application of nitrogen and potash. Nitrogen may be supplied in the form of ammonium sulphate 300 to 1000 gm per seedling per year depending upon the age of the seedling, preferably in two split dosage. The recommended fertilizer application for coconut plantation as per their growth stage is given in Table 4-5. In addition, farm yard manure @50 kg/palm/year is recommended during April-May. It is recommended that wood ash at 10-20 kg may be used instead of 1 kg of muriate of potash (Table 6). An occasional dressing of about 0.25 to o.5 kg of superphosphate per seedling is also desirable for healthy growth.

Table 4. Fertilizer (g/plant) requirement for coconut based system

Planting year	Pre monsoon (April - May)			Post monsoon (Oct - Nov)		
	N	$P_2 0_5$	K_2O	N	$P_2 0_5$	K_2O
1st year of planting	Planting in May - June			50	30	135
2nd year after planting	50	35	150	110	60	270
3rd year after planting	110	70	300	220	120	540
4th year after planting	170	100	450	330	150	800

Table 5. Recommended fertilizer dosage for coconut based system

Age of plantation	Dosage (per palm per year)
After one year's growth	1/8 of the adult palm dosage
After two years's growth	¼ of the adult palm dosage
After three year's growth	1/2 of the adult palm dosage
After four year's growth	¾ of the adult palm dosage
After five year's growth and thereafter	Full of the adult palm dosage

Table 6. Recommended dosage of mixtures (kg/tree/year) for sandy soils

Mixture1	
Cattle manure or compost	25-50
Wood ash	10-20
Bone meal	1
Mixture 2	
Fish guano	7
Muriate of potash	1
Mixture 3	
Prawn dust	7
Muriate of potash	1
Oilcake	7-10
Wood ash	10-20
Bone meal	1

Plantation based integrated farming system is the key for enhanced productivity and regular income at farm level in coastal areas. The integrated farming also helps in maintaining good soil health through system management and ensures better environmental quality. Based on agro-ecosystem analysis of the prevailing farming systems in A&N Islands, four micro-farming situations were identified. Experiments were conducted in plantation based (integrated with backyard poultry and livestock) hilly micro farming situation apart from sloping hilly upland, medium upland valley and low-lying valley land areas. In this case, coconut and arecanut plantations were intercropped with black pepper, sapota and banana and integrated with 2 buffalo plus 3 calves and 50 backyard poultry birds. The total input and output energy from plantation plus fruit crops were estimated at 6,031 and 1,33,018 MJ whereas for cattle were 27993 and 9819 MJ and for poultry were 21751 and 2155 MJ. It gave a net return of Rs 3,26,408/- from plantation (83.5%) and Rs 64,300/- from livestock (13%) and poultry (3.5%). Further, considering the large area under coconut plantation and traditional pig farming in Car Nicobar, experiment is being conducted in 1 ha coconut plantation with integration 4 pigs based on energy requirement and rainwater harvesting in farm pond. Coconut plantation is intercropped with clove, nutmeg, colacasia, tapioca and pineapple for developing self sustainable farming system. The study revealed that integrated farming system is highly profitable as bay islands are rich in natural resources and weather is congenial for different enterprises integrated. Appropriate integration of components increased the production per unit area and reduced cost of production. However, there is need for optimal resource allocation with multi-objective optimization function so as to maximize the net farm returns within the resource constraints in sustainable manner.

Climate change on coastal agriculture: Action plan

The major economic activities in coastal areas are agriculture, animal husbandry, fishery and tourism. These areas entirely depend on rainfall for fresh water, which is severely scarce during dry period and not available for irrigation purposes. Any change in the pattern and quantum of rainfall, rise in temperature and sea level as a consequence of climatic change would lead to scarcity/excess of water in the form of frequent droughts/floods resulting damages to land, crops, animals affecting livelihood options in the islands. It can be inferred from the discussion made in the previous sections that the coastal region is highly sensitive to climate change. Therefore, it is urgently required to intensify in-depth research work with the following objectives:

- Analyse recent experiences in climate variability and extreme events, and their impacts on regional water resources and groundwater availability/quality.
- Study on changing patterns of rainfall, i.e. spatial and temporal variation and its impact on run-off and aquifer recharge pattern.
- Study sea-level rise due to increased run-off as projected due to glacial recession and increased rainfall
- Sea-water intrusions into costal aquifers.
- Determine vulnerability of regional water resources to climate change and identify key risks and prioritize adaptation responses.
- Evaluate the efficacy of various adaptation strategies or coping mechanisms that may reduce vulnerability of the regional water resources

Salt Tolerant Varieties

In the low-lying waterlogged salt affected lands, farmers grow tall, extremely long duration traditional paddy cultivar. It covers about 60-70% of the rice-cultivated area. The farmers can use long duration high yielding paddy varieties i.e. Ranjeet and Varshadhan in waterlogged areas. In saline areas, salt tolerant rice varieties (Table 7) and vegetable/fruit crops (Table 8) can give better yield performance.

Table 7. Recommended rice varieties for different land situations

HYV for unaffected areas	Salt tolerant cultivars
For mono-cropping: IET 9188, IET 7991, IET 8021	CSR 10, CSR 23, CSR 30, CSR 36, Canning 7 (CSSRI)
For double cropping: IET 11754, IR 18350-229-3, IR 31851-6-3-3-2-2 (Short duration); Quing Livan 1, Taichung Sen Yu, Milyang 55, Nanjing 47161 (Medium duration)	Vytilla 3, Vytilla 4, and Vytilla 5 (KAU) CO 43, TRY 1, Pokkali (TNAU); PSBRc 50, PSBRc 88, PSBRc 90 (IRRI);
	BTS 24, BRRI dhan40, BRRI dhan41 (BRRI)

Table 8. Vegetables and fruit crops with their salinity tolerance for coastal areas

Vegetable crops	Varieties	Salinity levels (dS/m)
Brinjal	Pusa hybrid 6 and Pusa Uphar	8
Tomato	Pusa Ruby, Pusa 120 and Pusa Rohino	8
Chilli	CA 960, Suryamukhi and Pusa Jwala	7
Watermelon	Sugar sweet and Sugar Baby	6
Sapota	Badami, Cricket ball and Kalapatti	10
Guava	KG, Kashi and L-49	6

Improving Agricultural Productivity in Coastal Region - Some Issues

Coastal areas are highly fertile and rich in natural resources but are fragile in nature noth due to natural and anthropogenic reasons. Weather uncertainty and likely extreme weather events are expected to further influence the non-stabilized agricultural productivity in coastal region. Following are the water related issues, which require more focus in future research:

1. Database on crop/farm/system productivity for coastal districts are important to set the priority areas of concern in coastal eco-system.
2. Application of modern techniques such as remote sensing and geographical information system may be used in future coastal agricultural research. However, application of microwave remote sensing may be explored in combination of optical remote sensing due to continuous cloud cover in the coastal regions.
3. Monitoring of planned surface drainage improvement schemes would help in identifying the reasons of their poor performance and suggestive measures for their improvement.
4. Different farming system options, available in each coastal sub-region, may also be evaluated for water productivity apart from land productivity and their economics.
5. Land shaping interventions should be seen as mitigation measures in the wake of Sea level rise due to climate change and need to be evaluated at different sub-regions for suitable modification and adoption.

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Recent trends in Agricultural Water Management

T.B.S. Rajput

Emeritus Scientist, Water Technology Centre,
ICAR - Indian Agricultural Research Institute, New Delhi-110012
Email: tbsraj@iari.res.in

Introduction

Water is prime requirement for all aspects of life. It is imperative to make certain that adequate supplies of water of good quality are maintained for all the needs of entire population while preserving the hydrological and biological functions of ecosystems. Innovative technologies, including the improvements in the indigenous technologies, are needed to fully utilize limited water resources and to safeguard these resources against pollution. Irrigation sector being the main user of water resource, it is essential to modernize the irrigation system for optimal use of water resources by economizing water consumption per unit yield of agricultural produce. This involves not merely improvement of engineering parameters e.g. lining of canals / improvement of structures / providing additional field channels but also application of a complex combination of field disciplines (agronomic/management/field measurement and hydro-sociological aspects) to the irrigated agriculture sector. Several alternative technological solutions have been attempted by many researchers. Some of the important efforts made in agricultural water management are presented and discussed in this note.

India's water resources

Rainfall is the major source of water over the country barring a limited quantity of snow that occurs in the Himalayan region in the north. The rainfall over India is characterised by wide spatial and temporal variations. The annual rainfall varies from a about 310 mm in western Rajasthan to over 11400 mm in Meghalaya with an average value of 1170 mm for the entire country. About 85 percent of this rainfall occurs during four to five months of the year. The annual precipitation occurring over the geographical area of 329 mha of the country amounts to 4000 Billion Cubic Meters (BCM). The average annual run-off in the rivers of the country is assessed as 1869 BCM, of which, only 690 BCM of surface water and can be beneficially harnessed through the presently available technology, while the total renewable groundwater resource is estimated to be about 431.8 BCM. Thus the total annual renewable utilizable water resources of the country are put at 1122 BCM. In addition, about 200-250 BCM of water can be utilised through inter basin transfers. On completing all the on going and contemplated new projects, total storage capacity, excluding minor storages, of the country is likely to reach 382 BCM.

Water needs

The projected food-grain and feed demand for 2025 is estimated as 310-320 million tones. The requirement of food grains for the year 2050 would be as high as 420-490 million tones. Table 1 provides details of the population of India and per capita water availability as well as utilizable surface water for some of the years from 1951 to 2050 (projected). The availability of water in India shows wide spatial and temporal variations. Also, there are very large inter annual variations.

Table 1. Annual water requirement for different uses (in cubic km)

Use	Year 1997-98	Year 2010			Year 2025			Year 2050		
		Low	High	%	Low	High	%	Low	High	%
Surface Water										
Irrigation	318	330	339	48	325	366	43	375	463	39
Domestic	17	23	24	3	30	36	5	48	65	6
Industries	21	26	26	4	47	47	6	57	57	5
Power	7	14	15	2	25	26	3	50	56	5
Inland navigation		7	7	1	10	10	1	15	15	1
Environment-Ecology		5	5	1	10	10	1	20	20	2
Evaporation Losses	36	42	42	6	50	50	6	76	76	6
Total	399	447	458	65	497	545	65	641	752	64
Groundwater										
Irrigation	206	213	218	31	236	245	29	253	344	29
Domestic	13	19	19	2	25	26	3	42	46	4
Industries	9	11	11	1	20	20	2	24	24	2
Power	2	4	4	1	6	7	1	13	14	1
Total	**230**	**247**	**252**	**35**	**287**	**298**	**35**	**332**	**428**	**36**

Need for water saving technologies

The overall efficiency in most irrigation systems is low and in the range of 35 percent to 40 percent efficiency in surface water and 65-70 percent efficiency in ground water utilization. Being, major consumer of water, even a marginal improvement in the efficiency of water use in irrigation sector will result in saving of substantial quantity of water which can be utilized either for extending irrigated area or for diverting the saving to other sectors of water use. Different modern and innovative approaches may be adopted in i) water conservation, ii) water harvesting and storage, iii) land preparation, iv) water conveyance network, v) water application and vi) automation.

Water conservation

In low rainfall regions depending on the rainfall pattern different techniques of in situ soil moisture conservation water harvesting techniques may be adopted. Different type of agronomic practices such as contour farming and different kinds of mulching may be adopted. Zero tillage and conservation agriculture also help in improving water use efficiency in agriculture.

Water harvesting and storage

In the regions receiving runoff generating rainfalls water harvesting techniques may be adopted. Different type of innovative lining material is available for effectively and economically storing the harvested water. Multiple uses of water suing the storage for other productive uses such as fishery before using the same water for irrigation appears a potentially viable option. Harvesting rainwater not only reduces the possibility of flooding, but also decreases the community's dependence on groundwater for domestic uses. Apart from bridging the demand–supply gap, recharging improves the quality of groundwater, raises the water table in wells/bore-wells and prevents flooding and choking of drains. These days rainwater harvesting is being taken up on a massive scale in many states in India. The estimated potentials of small-scale water harvesting structures in different rainfall zones are given in Table 2.

Table 2. Potential rainwater storage through small-scale water harvesting structures

Rainfall zone (mm)	Geographical area (Mha)	Harvestable runoff through water harvesting structure, (Mha-m)
100-500	52.07	0.78
500-750	40.26	1.51
750-1000	65.86	4.03
1000-2500	137.24	14.61
>2500	32.57	3.26
Total		**23.99**

It is not possible to enhance precipitation, but is possible to reduce water losses in the form of evaporation and runoff of surface water, and to increase the availability of renewable supplies by various artificial recharge methods. The development and augmentation of ground water resources shall need to be planned in an optimal manner by adopting appropriate techniques of water conservation and management.

Conjunctive use of surface and groundwater

Ground water resource is an important component of total water resource. The first rule for ground water exploitation is not to exceed its recharge for its long-term sustainable use. Ground water may be used alone and in conjunction with available surface water. Since ground water needs to be pumped for application on the surface. The same pumping unit may be used to develop some extra pressure so as to adopt pressurized irrigation water application methods. Besides offering a good control on its application pressurized irrigation methods do attempt to achieve higher efficiencies and in turn higher productivity of water. Thus, the optimal conjunctive use of the region's surface and groundwater resources would help in minimizing the problems of waterlogging and groundwater mining.

Recycle and reuse of water

Another way through which we can improve freshwater availability is by recycle and reuse of water. It is said that in the city of Frankfurt, Germany, every drop of water is recycled eight times. Use of water of lesser quality, such as reclaimed wastewater, for cooling and fire fighting is an attractive option for large and complex industries to reduce their water costs, increase production and decrease the consumption of energy. This conserves better quality waters for potable uses. Currently, recycling of water is not practiced on a large scale in India and there is considerable scope and incentive to use this alternative.

Scope for Improvement in canal water management

Evaluation of the delivery system at watercourse level indicates that the performance of the system is less than satisfactory as the system is not meeting its objective of equitable distribution of water amongst the users at times when needed by the crops and in a manner that would permit its efficient application. The major drawbacks that can be easily identified from the performance evaluation are:

- Lack of volumetric equity, which is mainly due to non-compensation of time for the water lost in conveyance and larger size unit command areas, which further aggravate the problem.
- Temporal mismatch between supply and demand. This is mainly due to system capacity constraint, which makes it difficult to meet peak demand efficiently. Also fixed frequency schedules that are in vogue do not necessarily match with the demand for water.

These problems are amenable to solution with certain modification in the existing system. Some of the suggested improvements are as follows:

- Inter and intra seasonal modifications in the rotational warabandi schedules.
- Introduction of auxiliary storage or service reservoir both at outlet and/or farm level.
- Allocation of canal water in conjunction with groundwater.
- Modification in the canal capacity factors.
- Appropriate sizing of watercourse or unit command area.
- Variable time warabandi schedule. If these interventions are implemented earnestly canal management would be greatly improved.

Land preparation

Field topography needs to be manipulated to make it smooth to receive and distribute water efficiently for which land leveling is practiced. Laser land leveling is becoming increasingly popular among farmers for precise land leveling. Precise land leveling not only saves water but adds to increase in crop productivity and nutrient use efficiency too. Precise land leveling also permits lesser bunds in the field resulting in saving of cultivable land as well.

The laser leveling system requires a laser transmitter, a laser receiver, an electrical control panel and a twin solenoid hydraulic control valve. The laser transmitter transmits a laser beam, which is intercepted by the laser receiver mounted on the leveling bucket (Fig 1). The control panel mounted on the tractor interprets the signal from the receiver and opens or closes the hydraulic control valve, which will raise or lower the bucket. Some laser transmitters have the ability to operate over graded slopes ranging from 0.01% to 15% and apply dual controlled slope in the field.

Water conveyance network

The lack of well maintained media of conveyance of water from the outlet to property heads remains a major bottleneck in the efficient functioning of the canal irrigation systems in the country. It has been observed that for most of the fields the watercourses do not exist even.

Watercourses should touch each holding with at least one delivery point fFor successful operation of any water distribution system,. To achieve this objective a complete network of water conveyance is required to connect the water source to each field. Minimal Spanning Tree model and Shortest Route Problem offer adoptable solutions for developing such networks. In open channel network different lining options are available for minimizing conveyance losses.

Another option for conveying irrigation water to a large number of fields in the command is to convey through underground pipelines. Underground pipelines can minimize total length of conveyance as there is no limitation of laying only on field boundaries and not through the field, as the underground pipe line can be installed through the fields too. It also avoids the problems of land acquisition for laying conveyance network. It also saves 5 to 7 per cent land that normally goes waste in laying surface conveyance system. Because of these advantages underground pipeline network is being preferred now a days in several canal command areas.

Fragmented land holdings with irregular field boundaries are a common feature of the canal command areas in the country. Scattered fields with irregular boundaries increase greatly the energy requirements in farming operations. They also require longer lengths of watercourses to convey water to different fields. They are often unsuitable to modern methods of water applications, like border strips and furrows. Converting the existing land into rectangular plots and their consolidation on ownership basis through suitable exchange between different owners are desirable features of an efficient on-farm water management program. Rectangulation of fields would not only provide for efficient mechanization but would also result into smaller lengths of watercourses. Rectangulation of fields would also enable the use of more efficient water application methods like border strips and furrows besides minimizing lengths of watercourses.

Watercourses account for water losses in excess of 20 per cent. Regular maintenance is the first step in terms of its reduction. Lining is the obvious answer but is expensive. Maintenance however, is the key for reduction in conveyance water losses in watercourses. Based on the available funds, appropriate criteria are available to decide for lining of different reaches of the watercourse for effectively minimizing the conveyance losses.

Seepage losses in the field watercourses are the single major cause of inequity in water distribution among different beneficiaries, even in those canal command areas where rotational water distribution system is in vogue. To achieve equity in water distribution and to save more than 20 per cent of the amount of water diverted from the canal system to different fields, lining of field watercourses becomes an obvious solution. For handling the discharges normally available at the field level, pre-cast concrete channel sections do become most suitable owing to their low-cost, effectiveness in seepage control and other operating advantages.

A properly designed water distribution system makes irrigation easy and efficient. Good irrigation structures are an essential part of an efficient irrigation layout. Efficient structures will save labour, land and water. An on-farm irrigation water distribution system comprises several intricate hydraulic structures such as conveyance channels, check gates, distribution boxes, falls, cutlets and siphons etc. complexities of their design and construction give rise to bottlenecks in the in-budget on-time completion of distribution network with sound workmanship. Several similar problems may be overcome by the use of the pre-cast concrete structures. The greatest advantage is the convenience of transporting a large assortment of these structures of remote and /or scattered areas often with different access and of their rapid installation with the help of only a few unskilled labourers.

At present, the water entering the canal network through the head works as well as the water getting distributed into the various branches and finally reaching the fields through the outlets are controlled manually. However, if these operations are carried out through automated electro-mechanical systems which can communicate to a central computer, then the whole process can be made more efficient. This would also help to save water and provide optimal utilization of the availability water.

Equity in water distribution

The question of equity becomes important in large water supply systems/ networks. Presently hardly any significant effort is made in ensuring equity in water distribution to different beneficiaries. Different computer based models namely OUTLET, EQUITA and SAMYA and others are available and may be made use of. Use of these models will ensure water ditrbutin equitably resulting in increased water productivity. It will also monimize the conflicts among the beneficiaries.

Water application at field

Water losses in application at field are very significant particularly in surface water application methods. Incientallly surface irrigation methods are followed in more than 90 per cent irrigated areas. Land leveling, smoothening, appropriate designs of borders, check basins and furrows, commensurate with soil type, land slope, available stream size besides the field length. Surge irrigation is the new concept in surface irrigation. In surge irrigation large stream sizes are applied in a discontinuous manner so as to take advantage of wetting by earlier application. Water application in cycles of on and off fasten the advance of water flow minimizing the time lag in water application at the head and tail ends of the field. Thus more uniform infiltration opportunity tie along the field length results in higher irrigation efficiencies.

Considerable savings in water can be achieved by adoption of sprinkler, drip/micro-sprinkler irrigation systems in water scarcity areas, having conditions conducive to their application. Actual field studies indicated water saving of 25 to 33 per cent and increased yield up to 35 percent with sprinkler system compared with normal surface irrigation method. Further, 10-16 percent more area is available for crops as channels and ridges are not required. In sprinkler method as the water is sprayed, some loss in evaporation takes place. Sprinkler, therefore, should be avoided in zones of high wind. This loss of water is, however, eliminated in drip method in which water is directly trickled in to the soil near the root zone of the crop resulting in considerable saving and is particularly more suitable to row crops. 25 to 60 percent water is saved in drip method and increased yield up to 60 percent is obtained compared with conventional surface irrigation methods.

Normal drip systems are costly as pressurized release of water is required in the emitters for serving the whole command. Simple and inexpensive drip irrigation system called "Bucket Kit" is also developed and is especially popular in African countries enabling women to grow vegetables during long dry seasons. The Bucket Kit drip system consists of 5 gallon bucket mounted one meter above ground and drip system covering total 30 meters to irrigate two/four or six rows of vegetables. The kit also includes a filter and necessary fittings. These kits save water, labour and are easy to use in small farms. In some of the systems overhead tanks are also used. About 2-3 m head available creates enough pressure to push water from one end of main pipe to the other end. Pitcher irrigation, a traditional Indian practice is also a variant of this method of drip irrigation. Micro sprinklers/ micro sprayers spray around the root zone of the trees with a small sprinkler which works under low pressure. This unit is fixed in a network of tubing but can be shifted from place to place around the area. This method is very much suited for tree/orchard crops. A recent development in micro irrigation is the LEPA system in which the micro sprinklers are installed downwards to sprinkle water under low pressure from about 10-15 cm above the ground surface. The irrigation efficiency of this method is reported to be as high as 97%.

Automation

Rapid advances in electronics and its successful use in developing auto irrigation system have made it possible to practice efficient irrigation. This is particularly true in case of micro irrigation systems which can be easily automated to schedule irrigation and do not depend upon irrigator's judgment. To maximize crop yield irrigation should be applied at appropriate values of soil water stress in the root zone which is dependent on soil type, crop and its stage on growth etc. It is very difficult to control irrigation as per the values of soil water stress manually. In automatic irrigation system soil water stress is sensed continuously by tensiometers/ other gadgets installed at suitable depths and location, the output of soil moisture stress monitors is converted into an electrical signal with the help of a transducer. Latest developments in automation include the adoption of phytomonitoring techniques to monitor the moisture stress in plant stem/ leaf/ fruit and use the same to control irrigation and fertigation for optimizing the use of water and fertilizers. Standard automation head units are commercially available particularly for sprinkler and drip irrigation to regulate water and fertilizer supplies to a crop.

Role of Water users' Association

Water users' Associations have been made in different states to manage irrigation water from outlets, minors and distributaries of the canal system. Farmers have also been involved in the management of irrigation water from tanks and deep tubewells. Involvement of water users associations in water management is hoped to achieve efficient water distribution thinking that the group in their own interest will monitor and maintain the system. The results have been mixed as at some places water users associations have performed well but at places their impact has not been noticeable. Usually the following role is expected from water users associations.

(i) To improve the water delivery service through better operation and maintenance.

(ii) To achieve optimum utilization of available water from canals, tanks and tubewells.

(iii) To achieve equity in the distribution of water amongst water users.

(iv) To optimize the conjunctive use of precipitation and groundwater with the water delivered from the canal system.

(v) To assist farmers in crop planning and frequency and duration of water supply.

(vi) To inculcate a sense of ownership and responsibility amongst the farmers and to ensure collection of water charges.

(vii) To develop professional relationship between the water users and state irrigation agencies.

(viii) To generate local resources in cash, kind or labour for operation and maintenance.

(ix) To assist farmers' association and its members in other spheres of activities (e.g. agro industries and marketing) for their upliftment.

Water Management is Key for Sustainable Development

K Yella Reddy

Director, Water and Land Management Training and Research Institute, Hyderabad

Email:yellark@gmail.com

Introduction

Next to air, the other important requirement for human life to exist is water. It is the Nature's free gift to human race. The use of water by man, plants and animals is universal. As a matter of fact every living soul requires water for its survival. The water plays important role in the agriculture, manufacture of essential commodities, generation of electricity, transportation, recreation, industrial activities, etc. The water can certainly inexhaustible gift of nature. But to ensure their services for all the time to come, it becomes necessary to maintain, conserve and use these resources very carefully in every sphere of life. When you know that nothing on Earth can live without freshwater, that a human can't survive after three days without it, you see how precious this resource is – and how much we need to protect it.

Limited fresh water

Average annual precipitation over the whole globe is about 86 cm, of which 77% falls on the oceans and 23% on land. Evaporation (including transpiration by plants) from the land accounts for 16% of the total precipitation it receives, and 7% of global precipitation returns to the sea as river and groundwater flows. Although water is the most widely occurring substance on Earth, only 3 % of it is fresh water and the remaining 97 % is saltwater (Fig 1). Of the small amount of freshwater, only one third is easily available for human consumption, the large majority being locked up in glaciers and snow cover.

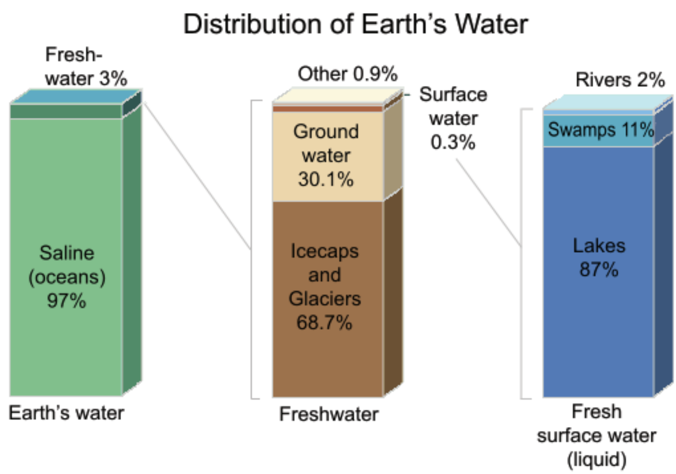

Fig 1. Distribution of earth's water showing limited fresh water for direct use

Water usage

Water is vital for sustaining life on earth. It is crucial for economic and social development, including energy production, agriculture and domestic and industrial water supplies. Therefore each unit of water should be used efficiently, equitably and soundly. Water is intrinsic to our lives and to the ecosystems on which we all depend. Water is essential to life in every way, we need clean water for drinking, adequate water for sanitation and hygiene, sufficient water for food and industrial production, and much of our energy generation relies on or affects water supplies. Demographic and urban growth over the next century will mean a far greater demand for water for industrial production. Competition between users, and sectors, is therefore becoming increasingly important. World's water usage pattern in the previous century, which is growing at alarming rate, is shown in Fig 2. During the past century, the world population has tripled, and water use has increased six-fold. These changes have come at great environmental cost: half the wetlands have disappeared during the 20th century, some rivers don't reach the sea anymore, and 20% of freshwater fish are endangered. The variation of water use for agriculture, industry and domestic use across the continents is shown in Fig 3.

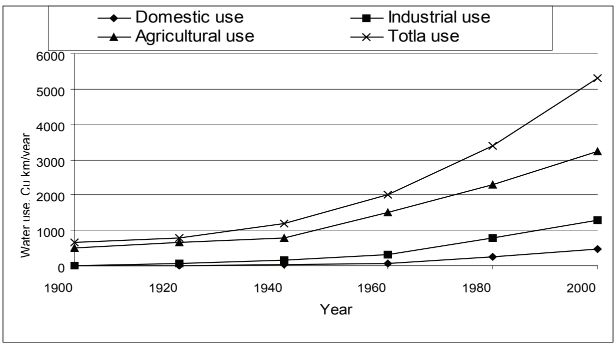

Fig 2. World's water use pattern in 20th century

In India more than 82% of the total water is used for agriculture with very low irrigation efficiencies. It is expected that in the next 7-8 years, there will be cut of about 10% irrigation water for meeting ever-increasing demand from domestic, industrial and other sectors.

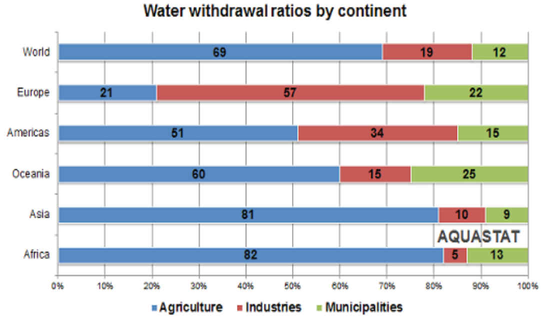

Fig 3. Continental wise water usage pattern for important sectors

Water scarcity

When country's renewable water supplies drop below about 1700 cubic meters per capita, it becomes difficult for that country to mobilize enough water to satisfy all the food, household, and industrial needs of its population. Countries in this situation typically begin to import grain, reserving their water for household and industrial uses. At present, 34 countries in Asia, Africa, and Middle East are classified as water stressed, and all but two of them-South Africa and Syria are net importers of grain. Collectively, these water stressed countries import nearly 50 million tons of grain a year. By 2025, the number of people living in water stressed countries is projected to climb from 470 million to 3 billion- more than six fold increase. The growing water scarcity by the year 2050 is shown in Fig 4.

Increasing population and higher levels of human activities, including effluent disposals to surface and groundwater sources, have made sustainable management of water resources a very complex task throughout the world. In addition, per capita demand for water in most countries is steadily increasing as more and more people achieve higher standards of living and as lifestyles are changing rapidly. Table 1 shows the population growth, annual renewable freshwater available and per capita availability for selected countries (Biswas, 1998).

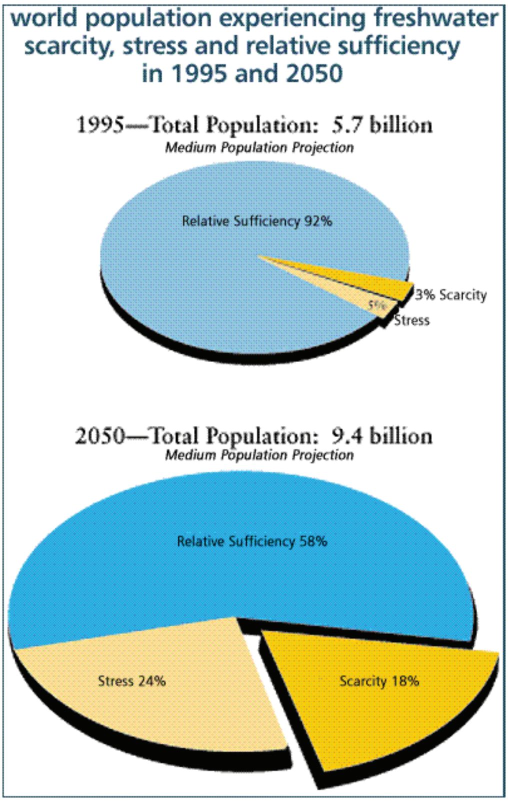

Fig 4. Growing water scarcity

Table 1. Population and per capita water availability for selected countries

Country	Population, Millions			Fresh water, km^3	Per capita fresh water, 1000 m^3		
	1994	2025	2050		1994	2025	2050
Brazil	150.1	230.3	264.3	6950	46.30	30.18	26.30
Canada	29.1	38.3	39.9	2901	99.69	75.74	72.70
China	1190.9	1526.1	1606.0	2800	2.35	1.83	1.74
Indonesia	189.9	275.6	318.8	2530	13.32	9.17	7.94
USA	260.6	331.2	349.0	2478	9.51	7.48	7.10
Bangladesh	117.8	196.1	238.5	2357	20.00	12.02	9.88
India	**913.6**	**1392.1**	**1639.1**	**2085**	**2.28**	**1.50**	**1.27**
Argentina	34.2	46.1	53.1	994	29.06	21.56	18.71
Japan	124.8	121.6	110.0	547	4.38	4.50	4.97
Turkey	60.8	90.9	106.3	203	3.34	2.23	1.91
UK	58.1	61.5	61.6	120	2.07	1.95	1.95
Egypt	57.6	97.3	117.4	59	1.02	0.60	0.50

India, with 2085 km^3 of renewable water resources stands 7th in the world, but due to its huge population over 1 billion, it attained 133rd position in terms of per capita availability of water. India has moved from the relative sufficiency level to stress and heading towards scarcity.

Resource under pressure

Groundwater is one of the most valuable natural resources possessed by many developing nations. Without pro-active management and protection there is a serious risk of irreversible deterioration on an increasingly widespread basis. Groundwater has many advantages over surface water for water supply:

i) It is reliable in dry seasons or droughts because of the large storage.

ii) It is cheaper to develop, since, unpolluted, it requires little treatment.

iii) It can often be tapped where it is needed, on a stage-by-stage basis.

iv) It is less affected by catastrophic events.

As a result groundwater has become immensely important for human water supply in urban and rural areas in developed and developing nations alike. Groundwater is now being abstracted at unsustainable rates in many areas, seriously depleting reserves. This happens when uncontrolled drilling of wells causes the overall rates of withdrawal from aquifers greatly to exceed their replenishment from rainfall and other sources over decades or more. This ‘over-abstraction’ causes many serious problems. Often the yield of wells is reduced and the cost of pumping increased. In extreme cases, this may lead to the wells being abandoned, with premature loss of infrastructure investment.

Effects of falling water tables

Lowering the groundwater level by one metre adds one metric ton of load per square metre to the subsoil.

i) In Gujarat in northern India, groundwater supplies most domestic and more than three quarters of irrigation water. Over-abstraction has caused the water table to fall, in some places by as much as 40 metres. This has deprived many poor farmers of water since they can afford only dug wells, which are usually limited to depths of 10 metres.

ii) In Mexico City the water table has fallen so low that there has been widespread ground subsidence, involving costly rebuilding.

iii) Parts of the Las Vegas valley, in the United States have fallen by more than 1.5 metres as a result of over-abstraction in an area where annual rainfall averages only 100 mm. Arizona is marked by a series of hundreds of fissures in the ground, which have disrupted roads, railways and housing.

iv) In the southern province of Brabant, in the Netherlands farmers are not allowed to use groundwater for irrigation in part of the year, as over-abstraction is causing drying out of the local ecology.

v) Bangkok is suffering from severe water problems as a result of the over-exploitation of the water table beneath the city.

vi) In Beijing recently, over-abstraction caused the water table to drop by more than four metres in a year.

vii) In many places of the world salt water has been moving in land and polluting coastal aquifers. This saltwater intrusion problem is for example happening in India, China, Mexico and the Philippines.

viii) In Madras in India salt water intrusion has moved 10 km inland, causing many irrigation wells to be abandoned.

Virtual water

The Water Footprint and Virtual Water approaches are gaining importance for effective planning, development and management of water resources to improve the water use efficiency and enhance its productivity. The concept of virtual water links a large range of sectors and issues that revolve around relieving pressures on water resources, ensuring food security, developing global and regional water markets. The concept of virtual water emerged in the early 1990s and was first defined by Professor J.A. Allan as the 'water embedded in commodities'. Producing goods and services requires water; the water used to produce agricultural or industrial products is called the virtual water of the product.

Virtual water is an essential tool in calculating the real water use of a country, or its water footprint, which is equal to the total domestic use, plus the virtual water import, minus the virtual water export of a country. A nation's water footprint is a useful indicator of the demand it places on global water resources. By importing virtual water, water poor countries can relieve the pressure on their domestic water resources. At the individual level, the water footprint is equal to the total virtual water content of all products consumed. A meat diet implies a much larger water footprint than a vegetarian one, at an average of 3,500 liters of water per day versus 2,500. Being aware of our individual water footprint can help us use water more carefully. Virtual water of some of the important products is shown in the Table 2.

Table 2. Virtual water of some important products

Commodity	Virtual water
1 cup of coffee	140 liters
1 liter of milk	800 liters
1 kg maize	900 liters
1 kg of wheat	1100 liters
1 kg of rice	3000 liters
1 kg sugar	3200 liters
1 kg chicken	6000 liters
1 kg beef	16000 liters

For example, growing one ton of grain or wheat requires about 1,000 m^3 of water; growing the same amount of rice requires up to thrice as much. The value of the water used for producing these food staples in water-poor countries turns out to be many times higher than the value of the product. Thus, instead of using their scarce water resources for water-intensive products, such countries can import cheap food, and relieve the pressure on their own water resources. Already a number of countries, such as Israel and Jordan, have formulated policies to reduce export of water-intensive products. Currently, 60 to 90% of Jordan's domestic water is imported through virtual water. Still, some countries are afraid of becoming dependent on global trade – those with large populations, for example, such as China or India. What would happen if, for some reason, their food demands could not be met? This explains why they are trying, as far as possible, to fill their own food needs.

Trade in virtual water

Water moves from one country to other in the virtual form through goods and services. About 15% of the water used in the world is for export, in virtual form. Out of this

i) 67% of the global virtual water trade is related to international trade of crops

ii) 23% is related to trade of livestock and livestock products

iii) 10% is related to trade of industrial products.

Sustainable development

The World Commission on Development (known as Brundtland Commission) in 1987 coined a term 'Sustainable Development' and defined as 'Development that meets the need of the present without compromising the ability of the future generations to meet their own needs'. For example, if sustainable water development is considered, it has been known for more than a century that irrigation without appropriate drainage would result in water-logging and salinity, which would, in turn, progressively reduce agricultural yields over a period of time. Since, main objective of introducing irrigation is to increase agricultural yields, clearly any system that does not fulfill this purpose over the long term cannot be considered sustainable.

Dublin Principles

International Conference on Water and Environment (ICWE) held in Ireland in 1992 has made the following recommendations (Dublin Principles) indicating the importance of water for sustainable development.

1. Freshwater is a finite vulnerable resource, essential to sustain life, development and environment
2. Water development and management should be based on a participatory approach involving users, planners and policy makers at all levels
3. Women play a central part in the provision, management and safeguarding of water.
4. Water has an economic value in all its competing uses and should be recognized as an economic good.

Valuing water

National Water Policy also makes a mention about the value of water. At present the farmers pay about Rs 200 towards water charges for irrigating one acre of paddy. If water is charged on volumetric basis at 1 paisa a liter, it costs about Rs. 1, 20,000 for growing paddy in one hectare land (Rs. 48,000 per acre). It tells how valuable the water is and highlights the importance of arresting wastage of water in irrigation. By considering the present scarcity and growing demands of domestic, industry and other sectors, it is required to save water in irrigation and allocate to other sectors. One centimeter of water saved in one hectare area under irrigation projects is worth Rs 5,000, if that is supplied to other sectors @5 paisa a liter.

Water resources development in India

India is endowed with water as a precious natural resource; however, its variability in different regions and over time limits its use for different purposes. Central Water Commission (CWC) has assessed India's surface water potential at 1869 billion cubic meters (BCM), of which 690 BCM is considered utilizable; Central Ground Water Board (CGWB) has assessed additional replenishable groundwater resource as 433 BCM. The National Commission on Irrigation and Water Resources Development (NCIWRD) projected both low and high water use requirements for three scenarios of 2010, 2025 and 2050 as given in Table 3 and concluded that India would fully utilize its water resources by 2050.

Table 3. Gross water availability and requirements of all water use in India under different scenarios

Source	Average Annual Utilizable Water Availability* (BCM)	Requirements** (BCM)						
		1997	2010		2025		2050	
		Last Assessed	Low	High	Low	High	Low	High
Surface Water	690	399	447	456	497	545	641	752
Ground Water	433	230	247	252	287	298	332	428
Total	**1123**	**629**	**694**	**710**	**784**	**843**	**973**	**1180**
Return Flows (SW+GW)		96	116	110	107	125	123	169
Unutilized Surface Water		334	295	284	263	219	140	42
Unutilized Ground Water		219	203	202	146	149	96	33
Unutilized Total		553	498	486	409	368	236	75

Source: * - CWC & CGWB; ** - NCIWRD

Studies by the International Water Management Institute (Amarasinghe et al, 2007) found that as a result of rising water demand many river basins will be physically water scarce by 2050. Of the 19 river basins in India, 8 already have a potentially utilizable water resource of less than 1,000 m^3/capita, with a further 7 currently with less than 1,500 m^3/ha. Only the Narmada (2,448 m^3/capita) and the Mahanadi (2,341 m^3/capita) river basins have adequate water resources available into the foreseeable future. By 2050 10 river basins, with 75 percent of the total population, will have developed all of the potentially utilizable water resources with the consequence that water reallocation between sectors will be a necessary and common occurrence in these basins. It is predicted that in many basins groundwater, with the current levels of recharge and groundwater use patterns, will be in severe crisis; some already are at catchment and sub-basin level.

Lower performance of irrigation schemes

The Central Water Commission (CWC) carried out Water Use Efficiency (WUE) studies for 30 major and medium irrigation (MMI) schemes which were analyzed and reviewed. Improving the performance of completed MMI schemes has been the main focus of the National Water Mission (NWM) and the 12th Five Year Plan and set a target of increasing the WUE by 20%. The 12th FYP quotes figures from WUE studies carried out by the CWC on 30 MMI schemes in which the WUE on nine schemes was found to be less than 30 percent and the average 38 percent. The WUE values of 12 MMI schemes of Andhra Pradesh and Telangana states are presented in Table 4.

Table 4. Project wise WUE values of 12 MMI schemes of AP &Telangana

S. No.	Name of the project	Water Use Efficiency, %			
		Reservoir storage	Canal conveyance	On-farm application	Overall efficiency
1	Krishna Delta System	100	87.40	46.18	40.36
2	Godavari Delta System	100	83.21	46.09	45.05
3	KC Canal	NA	62.25	45.15	28.10
4	NSP	100	55.96	38.93	21.80
5	Nizamsagar	76	87.00	45.32	39.43
6	RDS	100	82.83	51.51	42.66
7	Somasila	72	56.30	31.84	18.00
8	SRSP	95	77.98	57.28	44.66
9	TBPHLC	43	80.90	58.32	47.13
10	TBPLLC	100	72.13	44.80	32.23
11	Vamsadhara	100	90.50	58.47	52.91
12	Yeleru	28	50.00	28.42	14.21

With the NWM and 12th FYP target the average figure would need to rise to 46%. In the CWC summary report (CWC, 2010) the results of the studies for each scheme are summarized and an overall summary provided of the common reasons for low water use efficiency and common recommendations for improvement (Table 5).

Table 5. Common reasons and recommendations for low WUE from studies of 30 Irrigation systems (CWC, 2010)

Common reasons for low WUE	Common recommendations for improvement of WUE
i) Damaged structures	i) Rehabilitation and restoration of damaged/silted canal system
ii) Silting in the canal system	ii) Proper and timely maintenance of the system Selective lining of the canal and distribution system
iii) Poor maintenance	iii) Realistic and scientific system operation
iv) Weed growth in the canal system	iv) Revision of cropping pattern, if needed
v) Seepage in the system	v) Restoration/provision of appropriate control structures
vi) Over-irrigation	vi) Efficient and reliable communication system
vii) Illiterate farmers	
viii) Changing the cropping pattern	

vii) Reliable and accurate water measuring system

viii) Conjunctive use of ground and surface water

ix) Regular revision of water rate

x) Encouragement for formation of Water Users' Association

xi) Training to farmers

xii) Micro-credit facilities

xiii) Agricultural extension services

xiv) Encouragement to farmers for raising livestock

National water policy (2012)

India recognizes water as a scarce national resource fundamental to life, livelihood, food security and sustainable development. Recognizing that the availability of utilizable water under further constraints is leading to competition among different users, there is a growing concern on spreading scarcity due to its life sustaining characteristics and its economic value, mismanagement, poor governance, minimum ecological needs, inefficient use and rising pollution. The National water Policy (NWP) thus takes cognizance of the situation and has sketched a framework of creation of a system of laws and institutions and has drawn a plan of action considering water as a unified resource.

a) ***Priority on use of water***

NWP recognized the need for different use and suggests optimized utilisations for diverse use for which awareness on water as a scarce resource should be fostered. Governance institutions must ensure access to a minimum quantity of potable water for essential health and hygiene to all its citizens at their household. Ecological needs should be determined through scientific studies and a portion of water in rivers should be kept aside to meet ecological requirements. Regulated use of ground water should also consider contribution of base-flow to the river during lean seasons through regulated ground water use.

b) ***NWP on impact of climate change***

NWP recognizes the importance of adaptation to the impacts of climate change by the community through resilient technologies and endorses adaptation to strategies on increasing storages, demand management, stake holder's participation, and paradigm shift in design of river valley projects in coping with strategies to mitigate the impacts of climate change.

c) ***Enhancing water availability for different use***

The availability of water should be periodically and scientifically reviewed and reassessed in various basins every five years considering changing trends in climate change and accounted for in the planning process. Integrated watershed development activities with groundwater perspectives need be adopted to enhance soil moisture, reduce sediment yield, and increase overall land use productivity of rural development schemes.

d) ***Demand management***

The policy recommends evolution of a system of benchmarks for water uses for different uses, water footprints, and water auditing to promote and incentivize efficient use of water with clear emphasis on improving 'project' and 'basin' water use efficiencies through appropriate water balance and water accounting studies. Institutional arrangements for promotion, regulation and evolving mechanisms for efficient use of water at basin/sub-basin level need be established.

e) ***Regulation of water prices***

A water regulatory authority should be established in each state to fix and periodically review and regulate the water tariff system and charges according to the principles of NWP. Volumetric assessment and allocation, entitlement and distribution should be the criteria to ensure equity, efficiency and economic principles. WUAs need be given statutory powers to collect and retain a portion of water charges and reuse of recycled water should be incentivized.

f) ***Project planning & implementation***

The policy document recognizes the need for planning the water resources projects as per efficiency benchmarks to address the challenge of impeding climate change factors. The projects should incorporate social and environmental aspects in addition to the techno-economic aspects through consultative processes with governments, local bodies, project affected people, beneficiaries and stakeholders.

g) ***Data base and information needs***

The policy stresses the need for establishing a 'national water informatics centre' to collect, collate and process all hydrologic and water related information and maintain all information in an open and transparent manner on a GIS platform.

h) ***Capacity building, research and training needs***

The NWP emphasizes on the need for continuous research and advancement of technology, implementing newer research findings, importance of water balance in spatial and temporal context, water auditing for projects and hydrological systems, bench marking and performance evaluation. Need for regular training of the manpower for skill in water management is also recognized.

The provisions of the new NWP are clearly endorsing the principles of IWRM and suggesting that the framework for water planning, development and management should be clearly governed by these principles.

ICID Vision 2030: A water secure world free of poverty and hunger

The International Commission on Irrigation and Drainage (ICID), established in 1950 is a leading scientific, technical, international not-for-profit organization. ICID is a professional network of experts from across the world in the field of irrigation, drainage, and flood management. The main mission is to promote 'Sustainable agriculture water management' to achieve 'Water secure world free of poverty and hunger through sustainable rural development'. ICID is a knowledge sharing platform dedicated to issues that covers the entire spectrum of agricultural water management practices. In addition, drainage of agricultural lands forms the core theme of commission's activities. Floods and drought; the two extremes of increasingly variable climate as a result of potential climate change, also form the focus of activities. Presently, ICID country membership network is spread over 76 countries across Africa, Americas, Asia and Oceania, and Europe, covering over 95% of the irrigated area of the world.

Water being a direct or indirect part of 7 out of 17 Sustainable Development Goals, assumes inclusive dimension both as a natural resource for rural development and an essential input commodity for industrial and human (life-style) consumption. Due to increasing industrial prosperity over the last several decades and demographic changes taking place around the world, urban oriented socio-economic considerations have started attracting greater attention of policy makers and investors at the direct cost of rural water issues. The newly emerging and competing demands for water, coupled with the uncertainty of impact of climate change on food productivity, have challenged the ICID stakeholders and partners to redouble their efforts. ICID Vision 2030 for a water secure world free of poverty and hunger through sustainable rural development through its mission to facilitate prudent AWM by encouraging interdisciplinary approaches to irrigation and drainage management is an expression of intent of the network to help various stakeholders in moving towards a 'World we Want'. ICID network, which serves National Committees (NCs), irrigation and drainage professionals, farmers, policy makers, irrigation and drainage industry, researchers and the academia, and the society at large, aims to advocate an enabling integrated policy environment for facilitating multi-disciplinary innovations to increase land, water and crop productivities in a sustainable manner in a changing climate.

Way forward

In view of the ever growing water demands for domestic use and commercial sectors, and by considering the present status of water use in the irrigation projects, there is an urgent need to improve water resources management and water productivity across all sectors. State Specific Action Plans are required to be developed based on the guidelines of the National Water Mission and Vision documents of organizations like International Commission on Irrigation and Drainage etc.

In order to reduce water withdrawals for irrigation, upgrading of irrigation infrastructure through rehabilitation and modernization should be given priority. Other aspects like timely maintenance of irrigation and drainage infrastructure, investment in water storage and water saving technologies, combating the twin menace of water logging and salinity through drainage are required.

Maximizing basin water productivity through multi-objective decision making process, developing a rapid innovative research agenda, capacity building at all levels and building of institutional support for local, regional and international markets will go a long way in achieving food and water security. External factors, like impacts of climate change, virtual water trade, changes in agriculture markets and the prices of commodities will influence agriculture growth and allied activities. Such changes will require additional adaptations in the development of water management measures to sustain global food production to desired levels and avoid the probability of a severe crisis in the coming years.

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Role of Conservation Agriculture in Improving Soil Health and Mitigating Climate Change

K.L. Sharma
Principal Scientist & Former National Fellow, ICAR
ICAR-Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad
Email:kl.sharma@icar.gov.in

Out of the 329 m ha of total geographical area of the country, about 120.7 m ha of is under the severe grip of degradation, of which 73.3 m ha is affected by water erosion, 12.4 m ha by wind erosion, 6.73 m ha by salinity and alkalinity and 25 m ha by soil acidity (Singh, 2010). Out of an estimated net cultivated area of about 142.2 m ha, only about 73 m ha is area is rainfed and is dependent on Rain God. The irrigated area produces about 56% of total food requirement of India. The remaining about 44% of the total food production is supported by rainfed agriculture. Most of the essential commodities such as coarse cereals (90%), pulses (87%), and oil seeds (74%) are produced from the rainfed agriculture. These statistics emphasise the role that rainfed regions play in ensuring food for the ever-rising population. Rainfall wise, 15 m ha area falls in a rainfall zone of <500mm, 15 m ha under 500 to 750 mm, 42 m ha under 750 to 1150 mm and 25 m ha under > 1150 mm rainfall. Predominant soil orders which represent semi-arid tropical region are Alfisols, Entisols, Vertisols and associated soils. Other soil orders such as Oxisols, Inceptisols and Aridisols also form a considerable part of rainfed agriculture. Most of the soils in rainfed regions are at the verge of degradation with low cropping intensity, relatively low organic matter status, poor soil physical health, low fertility, etc. The first predominant cause of soil degradation in rainfed regions undoubtedly is water erosion. The process of erosion sweeps away the topsoil along with organic matter and exposes the subsurface horizons. The second major indirect cause of degradation is loss of organic matter by virtue of temperature mediated fast decomposition of organic matter and robbing away of its fertility. Above all, the several other farming practices such as reckless tillage methods, harvest of every small component of biological produce and virtually no return of any plant residue back to the soil, burning of the existing residue in the field itself for preparation of clean seed bed, open grazing etc aggravate the process of soil degradation.

Land degradation and soil quality deterioration- predominant causes

The major reasons which degrade land, deteriorate soil quality and its productive capacity could be enumerated as: i) washing away of topsoil and organic matter associated with clay size fractions due to water erosion resulting in a 'big robbery in soil fertility', ii) intensive deep tillage and inversion tillage with moldboard and disc plough resulting in a) fast decomposition of remnants of crop residues which is catalyzed by high temperature, b) breaking of stable soil aggregates and aggravating the process of oxidation of entrapped organic C and c) disturbance to the habitat of soil micro flora and fauna and loss in microbial diversity, iii) dismally low levels of fertilizer application and widening of removal-use gap in plant nutrients, iv) mining and other commercial activities such as use of top soil for other than agricultural purpose, v) mono cropping without following any suitable rotation, vi) nutrient imbalance caused due to disproportionate use of primary, secondary and micronutrients, vii) no or low use of organic manures such as FYM, compost, vermi-compost and poor recycling of farm based crop residues because of competing demand for animal fodder and domestic fuel, viii) no or low green manuring as it competes with the regular crop for date of sowing and other resources, ix) poor nutrient use efficiency attributing to nutrient losses due to leaching, volatilization and denitrification, x) indiscriminate use of other agricultural inputs such as herbicides, pesticides, fungicides, etc., resulting in poor soil and water quality, xi) water logging, salinity and alkalinity and acid soils. Consequent to all these reasons, soils encounter diversity of constraints broadly on account of physical, chemical and biological soil health and ultimately end up with poor functional capacity (Sharma et al., 2007). Amidst, likely climate change, the degradation of land resource may escalate. In order to restore the quality of degraded soils and to prevent them from some further degradation, it is of paramount importance to focus on conservation agriculture practices on long-term basis.

There is no doubt that, agricultural management practices such as crop rotations, inclusion of legumes in cropping systems, addition of animal based manures, adoption of soil water conservation practices, various permutations and combinations of deep and shallow tillage, mulching of soils with in-situ grown and externally brought plant and leafy materials always remained the part and parcel of agriculture in India. Despite all these efforts, the concept of conservation farming could not be followed in an integrated manner to expect greater impact in terms of protecting the soil resource from degradative processes.

Likely effects of climate change on Agriculture in general and soil health in particular

Rao et al (2010), have reported that the major weather related risks in Agriculture could be as follows: Monsoons in India exhibits substantial inter-seasonal variations, associated with a variety of phenomena such as passage of monsoon disturbances associated with active phase and break monsoon periods whose periodicities vary from 3-5 and 10-15 days respectively. It is well noticed that summer monsoon rainfall in India varied from 604 to 1020 mm. The inter-seasonal variations in rainfall cause floods and droughts, which are the major climate risk factors in Indian Agriculture. The main unprecedented floods in India are mainly due to movement of cyclonic disturbances from Bay of Bengal and Arabian Sea on to the land masses during monsoon and post-monsoon seasons – and during break monsoon conditions in some parts of Uttar Pradesh and Bihar. The thunderstorms due to local weather conditions also damage agricultural crops in the form of flash floods. Beside floods, drought is a normal, repetitive feature of climate associated with deficiency of rainfall over extended period of time to different dryness levels describing its severity. During the period 1871 to 2009, there were 24 major drought years, defined as years with less than one standard deviation below the mean. Another important adverse effect of climate change could be unprecedented heat waves. Heat waves generally occur during summer season where the cropped land is mostly fallow, and therefore, their impact on agricultural crops is limited. However, these heat waves adversely affect orchards, livestock, poultry and rice nursery beds. The heat wave conditions during 2003 May in Andhra Pradesh and 2006 in Orissa are recent examples that have affected the economy to a greater extent. Also occurrence of heat waves in the northern parts during summer is common every year resulting in quite a good number of human deaths. Further, the water requirements of summer crops grown under irrigated conditions increase to a greater extent.

Another adverse effect of climate change is cold waves which mostly occur in northern states. The Northern states of Punjab, Haryana, U.P., Bihar and Rajasthan experience cold wave and ground frost like conditions during winter months of December and January almost every year. The occurrence of these waves has significantly increased in the recent past due to reported climatic changes at local, regional and global scales. Site-specific short-term fluctuations in lower temperatures and the associated phenomena of chilling, frost, fogginess and impaired sunshine may sometimes play havoc in an otherwise fairly stable cropping/farming system of a region.

i) Effect on overall soil quality

Climate change is likely to have a variety of impacts on soil quality. Soils vary depending on the climate and show a strong geographical correlation with climate. The key components of climate in soil formation are moisture and temperature. Temperature and moisture amounts cause different patterns of weathering and leaching. Wind redistributes sand and other particles especially in arid regions. The amount, intensity, timing, and kind of precipitation influence soil formation. Seasonal and daily changes in temperature affect moisture effectiveness, biological activity, rates of chemical reactions, and kinds of vegetation. Soils and climate are intimately linked. Climate change scenarios indicate increased rainfall intensity in winter and hotter, drier summers. Changing climate with prolonged periods of dry weather followed by intense rainfall could be a severe threat to soil resource. Climate has a direct influence on soil formation and cool, wet conditions and acidic parent material have resulted in the accumulation of organic matter. A changing climate could also impact the workability of mineral soils and susceptibility to poaching, erosion, compaction and water holding capacity. In areas where winter rainfall becomes heavier, some soils may become more susceptible to erosion. Other changes include the washing away of organic matter and leaching of nutrients and in some areas, particularly those facing an increase in drought conditions, saltier soils, etc.

Not only does climate influence soil properties, but also regulates climate via the uptake and release of greenhouse gases such as carbon dioxide, methane and nitrous oxide. Soil can act as a source and sink for carbon, depending on land use and climatic conditions. Land use change can trigger organic matter decomposition, primarily via land drainage and cultivation. Restoration and recreation of peat lands can result in increased methane emissions initially as soils become anaerobic, whereas in the longer term they become a sink for carbon as organic mater accumulates. Climatic factors have an important role in peat formation and it is thus highly likely that a changing climate will have significant impacts on this resource.

ii) Effect on soil organic carbon

In India, over two-thirds of the increase in atmospheric CO_2 during the past 20 years is due to fossil fuel burning. The rest is due to land-use change, especially deforestation, and to a lesser extent, cement production. Global average surface temperature increased 0.6 (0.2) ^{o}C in the 20th century and will increase by 1.4 to 5.8 ^{o}C by 2100. Estimates indicate that India's climate could become warmer under conditions of increased atmospheric carbon dioxide. The average temperature change is predicted to be in the range of 2.33^{o}C to 4.78^{o}C with a doubling in CO_2 concentrations. Over the past 100 years, mean surface temperatures have increased by 0.3-0.8°C across the region. The 1990s have been the hottest decade for a thousand years. The time taken for CO_2 to pass through the atmosphere varies widely, with a significant impact. It can take from 5 to 200 years to pass through the atmosphere, with an average of 100 years. This means that CO_2 emission produced 50 years ago still linger in atmosphere today. It also means that current emissions won't lose their deleterious effect until year 2104. Even though drastic measures to reduce climate emissions have been taken in recent years, climate change is impossible to prevent. As a result of increasing pressure from climate change on current key areas of food production, there might be a rising need for increased food production. The production of food more locally is also being promoted in an attempt to reduce food miles. To meet food production and security objectives, there might be the need to afford prime agricultural land more protection. The rise in temperatures will influence crop yields by shifting optimal crop growing seasons, changing patterns of precipitation and potential evapotranspiration, reducing winter storage of moisture in snow and glacier areas, shifting the habitat's of crops pests and diseases, affecting crop yields through the effects of carbon dioxide and temperature and reducing cropland through sea-level rise and vulnerability to flooding.

iii) Effect on soil fertility

No comprehensive study has yet been made of the impact of possible climatic changes on soils. Higher temperatures could increase the rate of microbial decomposition of organic matter, adversely affecting soil fertility in the long run. But increases in root biomass resulting from higher rates of photosynthesis could offset these effects. Higher temperatures could accelerate the cycling of nutrients in the soil, and more rapid root formation could promote more nitrogen fixation. But these benefits could be minor compared to the deleterious effects of changes in rainfall. For example, increased rainfall in regions that are already moist could lead to increased leaching of minerals, especially nitrates. In the Leningrad region of the USSR a one-third increase in rainfall (which is consistent with the GISS 2 x CO_2 scenario) is estimated to lead to falls in soil productivity of more than 20 per cent. Large increases in fertilizer applications would be necessary to restore productivity levels. Decreases in rainfall, particularly during summer, could have a more dramatic effect, through the increased frequency of dry spells leading to increased proneness to wind erosion. Susceptibility to wind erosion depends in part on cohesiveness of the soil (which is affected by precipitation effectiveness) and wind velocity.

Nitrogen availability is important to soil fertility, and N cycling is altered by human activity. Increasing atmospheric CO_2 concentrations, global warming and changes in precipitation patterns are likely to affect N processes and N pools in forest ecosystems. Temperature, precipitation, and inherent soil properties such as parent material may have caused differences in N pool size through interaction with biota. Keller et al., 2004 reported that climate change will directly affect carbon and nitrogen mineralization through changes in temperature and soil moisture, but it may also indirectly affect mineralization rates through changes in soil quality.

iv) Effect on biodiversity

Climate change is having a major impact on biodiversity and in turn biodiversity loss (in the form of carbon sequestration trees and plants) is a major driver of climate change. Land degradation such as soil erosion, deteriorating soil quality and desertification are driven by climate variability such as changes in rainfall, drought and floods. Degraded land releases more carbon and greenhouse gases back into the atmosphere and slowly kills off forests and other biodiversity that can sequester carbon, creating a feed back loop that intensifies climate change.

Importance of soil organic matter and carbon in soil

Soil organic matter, a most precious component of soil, is also considered as store house of many nutrients. It consists of a mixture of plant animal residues in various stages of decomposition, of substances synthesized chemically and biologically from the breakdown products, and of microorganisms and small animals and their decomposing remains. In simple terms, it can be classified into non-humic and humic substances. Non-humic substances include those with still recognizable physical and chemical characteristics such as carbohydrates, proteins, peptides, amino acids, fats, waxes, alkanes, and low molecular weight organic acids. Most of these compounds are attacked relatively readily by microorganisms in the soil and have a short survival period. The humic substances which form the major portion of organic matter in soil are characterized by amorphous, dark colored, hydrophilic, acidic, partly aromatic, chemically complex organic substances with molecular weight varying from few hundreds to several thousands. Humic substances are categorized into three parts: i) humic acid which is soluble in dilute alkali but is precipitated by acidification of the alkaline extract, ii) Fulvic acid which is the humic fraction that remains in solution when the alkaline extract is acidified and iii) humin, which is the humic fraction that cannot be extracted from the soil or sediment by dilute base and acid (Schnitzer, 1982). When plant and animal remains are recycled in soil, they undergo the various stages of microbial decomposition and humification. Since agricultural soils contain little litter and decomposed litter layers, SOM generally refers to non-humic substances which constitute 10-15% of total organic materials, and the humic substances which comprise the largest fraction (85-90%).

Organic matter (OM) is what makes the soil a living, dynamic system that supports all life. The significance of soil organic matter (SOM) accrues from the following facts:

- Organic matter is considered as a food /energy source for soil microorganisms and soil fauna. Without OM, the soil would be almost sterile and consequently, extremely infertile.
- It is the storehouse of many plant nutrients such as N, P, S and micronutrients and contributes significantly to the supply of these nutrients to higher plants. There is very little inorganic nitrogen in soils and much of it is obtained by transformation of the organic forms. Plants are therefore, dependent either directly or indirectly, for their nutritional requirement of nitrogen on SOM.
- SOM also plays an important role in improving the majority of soil physical properties such as soil structure, water holding capacity, porosity, infiltration, soil drainage, etc.
- Soil organic matter also helps in improving various chemical properties of soil. For example, the increased cation exchange capacity and enhanced ligancy help in trapping nutrient cations like potassium, calcium, magnesium, zinc, copper, iron, etc. Improved soil buffering is its another important contribution.

- A part from the nutrients within the soil organics themselves, SOM contributes to nutrient release from soil minerals by weathering reactions, and thus helps in nutrient availability in soils.
- Plant growth and development are benefited by the physiological actions of some organic materials that are directly taken up by plants.
- The organic substances also influence various soil processes leading to soil formation.
- Considering the importance of organic matter in improving majority of the soil functions, it is considered as panacea to many productivity linked soil constraints. Hence, it plays important role to improve soil resilience.

Organic matter-role in soil structure building and as store house of plant nutrients

It has been established that the organic matter content of agricultural soils is significantly correlated with their potential productivity, tilth and fertility. Although the amount of soil organic matter (SOM) in most semiarid dryland soils is relatively low ranging from typically less than 1%, its influence on soil properties is of major significance. Organic matter is the predominant material facilitating soil aggregation and structural stability even at low concentrations. Better soil structures helps in improved air and water relationships for root growth and in addition protect soils form wind and water erosion. The dark colour imparted by humic fraction of SOM increases the soils capacity to absorb heat and to warm rapidly in the spring. In semiarid regions with low or intermittent rainfall, organic matter is the major pool for some of the essential plant nutrients. The N, P, S contents of these soils average 0.12%, 0.05% and 0.03% respectively, with 95% of the N, 40% of the P and 90% of the S being associated with the organic matter component. Since the soil organic matter constitutes the predominant pool of plant nutrients, the decomposition and fluctuation within this pool are of major significance to nutrient storage and cycling. In many dryland cropping systems, depending on fertilizer additions and crop rotations, 50% or more of the nitrogen required by the crop comes from the mineralization of SOM. The microbial action that mediates this decomposition and nutrient release process is regulated by perturbations of the system such as wetting of dry soil, tillage, and addition and placement of residue. These types of perturbations affect the dynamics of SOM decomposition, the size of the microbial biomass pool and nutrient release (Smith and Elliott, 1990).

Change in organic matter status of soil

According to Ghosh and Bhradwaj, (2002), organic matter content in soils varies considerably and is largely dependent on the environmental conditions. Most of the cultivated soils in temperate regions contain high OM levels (5-10%) in their surface horizon, whereas similar soils in the tropics and semi-arid topics have only one-fifth or one-sixth as much (often less than 1%). These variations are attributed to certain 'factors of soil formation' as given below:

Organic matter= f (climate, time, vegetation, parent material, topography……).

According to Jenny, the order of importance of different soil forming factors in determining the organic matter content of soils is as follows: climate> vegetation > topography>parent material> age. Further, Theng et al., 1989 expressed that the overall importance of the environmental factors determining soil C content is in the following order: rainfall>pH>

clay content> temperature for tropical regions and rainfall> pH> temperature > clay content for temperate regions (Prasad and Power, 1997).

Effect of soil management on organic matter status

There are several reports on the influence of soil management practices on SOM. It has been understood that management practices can modify soil organic matter levels by affecting organic matter inputs and influencing to some extent the degree or potential for turnover. Results of long-term rotational experiments indicate that increasing C inputs (e.g. manure) can cause a gradual organic matter accumulation over time, especially in arable farming systems (Jenkinson, 1990). Soil management strategies used to enhance organic matter storage, where organic C inputs remain stable, involve practices that provide for cool wet conditions at the soil surface (i.e. change in soil microclimate) such as mulches, surface residue application and minimum or reduced tillage (Follett, 1993; Kern and Johnson, 1993). However, major short-term improvements in soil organic matter storage are dependent upon changes in vegetation or cropping practices, crop rotations, etc.

Soil capacity for organic matter storage

Carter, (1996) has comprehensively reviewed the storage capacity of organic matter in soils. He has emphasized that the amount of organic matter stored by any particular soil is dependent upon climate, soil type and landscape, type of vegetation and soil management practices. The influence of climate on soil organic matter storage can be expressed by the relationship between mean annual temperature and annual precipitation. Tate, (1992) and Cole et al., (1993) emphasized that the wet, cool climates tend to slow organic matter turnover and subsequently favour organic matter accumulation in soil while moist, warm or hot climates favour rapid decomposition. Generally, soil organic matter decomposition processes are strongly dependent upon the interaction between temperature and precipitation. The overall influence of climate, however, can be modified by soil type and landscape. Edaphic conditions, such as soil particle size, pH, quantity and type of clay minerals, and internal drainage can influence organic matter accumulation and storage. Such intrinsic properties can impact on organic matter storage and decomposition, either directly or indirectly, by modifying the soil chemical (Tate, 1992), physical and biological environment, and subsequently influencing the soil aggregation process (Oades and Waters, 1991; Robert and Chenu, 1992). Soil topography and drainage can also modify the macroclimate resulting in a range of microclimates across a landscape and subsequent differences in soil organic matter storage.

Within any one climatic zone, vegetation differences can have a major impact on soil organic matter accumulation. Differences in C fixing capacity and in C partitioning within plants resulting in concomitant differences in root biomass, shoot/root ratios, thickness of roots and amount of root exudates can influence organic matter mineralization and accumulation in soil (Juma, 1993). Shifts in use of vegetation can directly increase soil organic matter storage (Schlesinger, 1990). A combination of soil and vegetation factors can enhance organic C storage in some situations (e.g. Mollisols) (Scharpenseel et al., 1992). In many cases, however, vegetation effects are related to the high ratio of C to N in roots and other plant residues (compared to soil), and thus constitutes a temporary (i.e. non-sequestered) accumulation of organic matter subject to relatively rapid turnover and dependent on continual C inputs. Above all, management practices comprising of tillage and, residue recycling can help in improving organic C in soil to a considerable extent.

Conservation agriculture and its components

Conservation agriculture is a practice that reduces soil erosion, sustains soil fertility, improves water management and reduces production costs, making inputs and services affordable to small-scale farmers. Conservation agriculture is defined as a set of practices aimed at achieving the following three principles simultaneously: i) maintaining adequate soil cover, ii) disturbing the soil minimally, and iii) ensuring crop rotation and intercropping. Conservation agriculture as defined by Food and Agricultural Organizations (FAO) of the United Nations is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. It is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt the biological processes (Philip et al., 2007). Conservation agriculture, in broader sense includes all those practices of agriculture, which help in conserving the land and environment while achieving desirably sustainable yield levels. Tillage is one of the important pillars of conservation agriculture which disrupts inter dependent natural cycles of water, carbon and nitrogen. Conservation tillage is a generic term encompassing many different soil management practices. It is generally defined as 'any tillage system that reduces loss of soil or water relative to conventional tillage; mostly a form of non-inversion tillage allows protective amount of residue mulch on the surface (Mannering and Fenster, 1983).

Lal (1989) reported that the tillage system can be labeled as conservation tillage if it i) allows crop residues as surface mulch, ii) is effective in conserving soil and water, iii) maintains good soil structure and organic matter contents, iv) maintains desirably high and economic level of productivity, v) cut short the need for chemical amendments and pesticides, vi) preserves ecological stability and vii) minimizes the pollution of natural waters and environments. In order to ensure the above criteria in agriculture, there is a need to follow a range of cultural practices such as i) using crop residue as mulch, ii) adoption of non-inversions or no-tillage systems, iii) promotion of crop rotations by including cover crops, buffer strips, agroforestry, etc., iv) enhancement of infiltration capacity of soil through rotation with deep rooted perennials and modification of the root zone; v) enhancement in surface roughness of soil without jumping into fine tilth, vi) improvement in biological activity of soil fauna through soil surface management and vii) reducing cropping intensity to conserve soil and water resources and building up of soil fertility. The effects of conservation tillage on various soil properties, organic matter status, soil nutrient status and environmental quality have comprehensively reviewed by Blevins and Frye (1993), Lal (1989), Unger and McCalla (1980) and Unger (1990). From the various reviews, it is understood that no single tillage system is suitable for all soils and climatic conditions. The predominant advantages of the conservation tillage have been found in terms of soil erosion control, water conservation, less use of fossil fuels specifically for preparation of seed bed, reduced labour requirements, more timeliness of operations or greater flexibility in planting and harvesting operations that may facilitate double cropping, more intensive use of slopping lands and minimized risk of environmental pollution. Some of the discouraging and undesirable effects of conservation tillage has been reported as: (1) Increase in use of herbicides and consequently increased cost, (2) problems and difficulties in controlling of some of the infested weeds, (3) difficulty in managing poorly drained soils, (3) slower warming of temperate soils due to surface residue layer during winter and springs which delays germination and early growth. However, in tropics this negative aspect can become an asset in helping in maintaining relatively lower temperature and thereby enhancing germination. It also helps in preserving soil and water resources.

Importance and scope of conservation agricultural practices in rainfed areas

As discussed in the foregoing section, soil quality degradation is more prominent in rainfed agro-eco-regions because of natural and human induced crop husbandry practices, which call for the adherence to the conservation agriculture management as top priority. Conservation agriculture has the main aim of protecting the soil from erosion and maintaining, restoring and improving soil organic carbon status in the various production systems, hence more suited and required in rainfed agriculture. Predominantly, this goal can be achieved through minimizing the soil tillage, inclusion of crop rotation or cover crops (mostly legumes) and maintaining continuous residue cover on soil surface. The former is governed by the amount of draft, a farmer is using and the latter by the produce amount, harvesting index and fodder requirements including open grazing. The crop rotations are induced by crop diversification, which has wider scopes in the rainfed agriculture than in irrigated agriculture. Diversification will help not only in minimizing the risk occurred due to failure of crops, improving total farm income but also in carbon sequestration.

Tillage, which is one of the predominant pillars of conservation agriculture, disrupts the inter-dependent natural cycles of water carbon and nitrogen. Tillage unlocks the potential microbial activity by creating more reactive surface area for gas exchange on soil aggregates that are exposed to higher ambient oxygen concentration (21%).Tillage also breaks the aggregate to expose fresh surfaces for enhanced gas exchange and perhaps, may lead to more carbon loss from the interior that may have higher carbon-dioxide concentration. Thus, an intensive tillage creates negative conditions for carbon sequestration and microbial activity. However, the main question is whether the intensity of tillage or length of cultivation of land which is an environment enemy in production agriculture in terms of loss of carbon-dioxide, soil moisture through evaporation and biota dwindling is a major production constraint to agriculture or not. The developed countries suffer from heavy-duty mechanization, while India is suffering from long use of plough without caring much about the maintenance of land cover. The major toll of organic C in slopping lands has been taken by water erosion due to faulty methods of up and down cultivation.

Conservation agriculture vis-à-vis soil quality

Various research reports have emphasized that conservation agricultural practices play an important role in preventing the soils from further degradation and in restoring back the dynamic attributes of soil quality. According to Doran and Parkin (1994) and Karlen et al., (1997), soil quality is defined as the functional capacity of the soil. Seybold et al., (1998) defined the soil quality as ‘the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation.' Quality with respect to soil can be viewed in two ways: (1) as inherent properties of a soil; and (2) as the dynamic nature of soils as influenced by climate, and human use and management. This view of soil quality requires a reference condition for each kind of soil with which changes in soil condition are compared and is currently the focal point for the term 'soil quality'. The soil quality as influenced by management practices can be measured quantitatively using physical, chemical and biological properties of soils as these properties interact in a complex way to give a soil its quality or capacity to function. Thus, soil quality cannot be measured directly, but must be inferred from measuring changes in its attributes or attributes of the ecosystem, referred to as 'indicators'. Indicators of soil quality should give some measure of the capacity of the soil to function with respect to plant and biological productivity, environmental quality and human and animal health. Indicators are measurable properties of soil or plants that provide clues about how well the soil can function. They provide signal about desirable or undesirable changes in land and vegetation management that have occurred or may occur in the future. Some of the important indicators which are given below can be influenced by appropriate soil management practices which in turn can help in moderating the ill effects of climate change (Table1).

Table 1: Major soil quality indicators and related processes and functions which can moderate the ill effects of climate change.

Soil quality indicators	Soil processes and functions
i) Physical indicators	
A. Mechanical	
Texture	Crusting, gaseous diffusion, infiltration
Bulk density	Compaction, root growth, infiltration
Aggregation	Erosion, crusting, infiltration, gaseous diffusion
Pore size distribution and continuity	Water retention and transmission, root growth, and gaseous exchange
B. Hydrological	
Available water capacity	Drought stress, biomass production, soil organic matter content
Non-limiting water range	Drought, water imbalance, soil structure
Infiltration rate	Runoff, erosion, leaching
C. Rooting zone	
Effective rooting depth	Root growth, nutrient and water use efficiencies
Soil temperature	Heat flux, soil warming activity and species diversity of soil fauna
ii) Chemical indictors	
pH	Acidification and soil reaction, nutrient availability
Base saturation	Absorption and desorption, solubilization

Cation exchange capacity	Ion exchange, leaching
Total and plant available nutrients	Soil fertility, nutrient reserves
iii) Biological indicators	
Soil organic matter	Structural formation, mineralization, biomass carbon, nutrient retention
Earthworm population and other soil macro fauna and activity	Nutrient cycling, organic matter decomposition, formation of soil structure
Soil biomass carbon	Microbial transformations and respiration, formation of soil structure and organic-mineral complexes
Total soil organic carbon	Soil nutrient source and sink, biomass carbon, soil respiration and gaseous fluxes

Source: Lal (1994)

Role of conservation agriculture in improving soil health and mitigation and adaptation climate change

There are predictions that as a consequence of the climate change, there is high probability of increase in temperature, heavy rainfall, frequent drought, floods, higher rates of green house gas (GHG) emissions, etc. In this context, CA has a vital role to play as mitigation and adaptation for extreme events occurring due to climate change. CA will help in mitigating atmospheric GHGs, by reducing fuel emissions as a result of reduced tillage operation and more sequestering of organic C in soil. According to According to Baker *et al.*100, adoption of conservation tillage in all the crop land could potentially sequester 25 Gt C over the next 50 years, which is equivalent to 1833 Mt CO2- eq year–1. Thus, adoption of conservation tillage practices can provide a vital path for stabilization of GHG emissions globally. CA also acts as a strong adaptation strategy to manage extreme climatic events such as wind and water erosion, because in this system, soil is protected by crop residues, and not frequently loosened by tillage. Moreover, improved soil aggregation makes it more resistant towards wind and water erosion. Improved soil moisture status and decreased evaporation loss might mitigate drought situations. These practices also help in regulating the extreme temperature flow (heat/frost) in soil by covering the soil surface. Another important beneficial aspect of conservation agriculture is that it can help in improving water infiltration into soil and enhances groundwater recharge with rain water, consequently reducing flood and erosion problems during heavy rainfall. Thus conservation agriculture practices can contribute significantly to make crop systems more resilient to climate change.

Some of the specific advantage of conservation agriculture in protecting the soil from further degradation and improving its quality are as follows:

- ***Soil Temperature**:* Surface residues significantly affect soil temperature by balancing radiant energy and insulation action. Radiant energy is balanced by reflection, heating of soil and air and evaporation of soil water. Reflection is more from bright residue.

- ***Soil aggregation:*** It refers to binding together of soil particles into secondary units. Water stable aggregates help in maintaining good infiltration rate, good structure, protection from wind and water erosion. Aggregates binding substances are mineral substances and organic substances. Organic substances are derived from fungi, bacteria, actinomycetes, earthworms and other forms through their feeding and other actions. Plants themselves may directly affect aggregation through exudates from roots, leaves and stems, leachates from weathering and decaying plant materials, canopies and surface residues that protect aggregates against breakdown with raindrop impact, abrasion by wind borne soil and dispersion by flowing water and root action. Aggregates with. 0.84 mm in diameter is non-erodable by wind and water action. Well-aggregated soil has greater water entry at the surface, better aeration, and more water-holding capacity than poorly aggregated soil.
- ***Aggregation:*** Aggregation is closely associated with biological activity and the level of organic matter in the soil. The gluey substances that bind components into aggregates are created largely by the various living organisms present in healthy soil. Therefore, aggregation is increased by practices that favor soil biota. Because the binding substances are themselves susceptible to microbial degradation, organic matter needs to be replenished to maintain aggregation. To conserve aggregates once they are formed, minimize the factors that degrade and destroy them.
- ***Well-aggregated soil also resists surface crusting:*** The impact of raindrops causes crusting on poorly aggregated soil by disbursing clay particles on the soil surface, clogging the pores immediately beneath, sealing them as the soil dries. Subsequent rainfall is much more likely to run off than to flow into the soil. In contrast, a well-aggregated soil resists crusting because the water-stable aggregates are less likely to break apart when a raindrop hits them. Any management practice that protects the soil from raindrop impact will decrease crusting and increase water flow into the soil. Mulches and cover crops serve this purpose well, as do no-till practices which allow the accumulation of surface residue.
- ***Soil density and porosity:*** Soil bulk density and porosity are inversely related. Tillage layer density is lower in ploughed than unploughed (area in grass, low tillage area etc). When residues are involved, tilled soils will reflect lower density. Mechanization with heavy machinery results in soil compaction, which is undesirable and is associated with increased bulk density and decreased porosity. Natural compaction occurs in soils, which are low in organic matter and requires loosening. But, practicing conservation tillage to offset the compaction will be effective only when there is adequate residue, while intensive tillage may adversely influence the soil fauna, which indirectly influence the soil bulk density and porosity.
- ***Effects on other physical properties:*** Tillage also influences crusting, hydraulic conductivity and water storage capacity. It has been understood that the textural influences and changes in proportion of sand, silt and clay occur due to inversion and mixing caused by different tillage instruments, tillage depth, mode of operation and effect of soil erosion. Soil crusting which severely affects germination and emergence of seedling is caused due to aggregate dispersion and soil particles resorting and rearrangement during rainstorm followed by drying. Conservation tillage and surface residue help in protecting the dispersion of soil aggregates and helps in increasing

saturated hydraulic conductivity. Increased HC in conjunction with increased infiltration resulting from conservation tillage allows soil profile to be more readily filled with water. Further, less evaporation is also supported by conservation tillage, and profile can retain more water.

Effect on soil organic matter and soil fertility

Conservation agricultural practices help in improving soil organic matter by way of i) regular addition of organic wastes and residues, use of green manures, legumes in the rotation, reduced tillage, use of fertilizers, and supplemental irrigation ii) drilling the seed without disturbance to soil and adding fertilizer through drill following chemical weed control and iii) maintaining surface residue, practicing reduced tillage, recycling of residues, inclusion of legumes in crop rotation. These practices provide great opportunity in maintaining and restoring soil quality in terms of SOM and N in SAT regions. It is absolutely necessary to spare some residue for soil application, which will help in improving soil tilth, fertility and productivity.

How carbon is sequestered in soil - mechanism

The information pertaining to mechanism of carbon sequestration along with effective techniques has been comprehensively reviewed by (Lal & Kimble, 1997). According to these authors, dynamics of Soil Organic Carbon (SOC), that determines the equilibrium status, depends on many factors including soil properties and especially the aggregation. It is the increase in amount of SOC in slow or inactive pool that is an important factor in C sequestration, and the slow pool may be involved in aggregation. Therefore, improved SOC reserves may imply increasing the slow or resistant pool. There are two strategies or mechanisms of C sequestration: (i) increasing stable proportion of macro- and micro-aggregates, and (ii) deep placement of SOC in the sub-soil horizons with sub-surface incorporation of biomass. Cementation of primary particles and clay domains and micro-aggregates is based on formation of organo-mineral complexes. These complexes bind clay into aggregates, thereby immobilizing and sequestering the C. There are several techniques for improving micro-aggregation. However, these techniques are soil and ecoregion specific. There are several reports on the effects of management practices on soil aggregation and carbon sequestration. Resck et al. (1991), while working in the Cerrado region of Brazil reported that the continuous cultivation for 11 years altered aggregate size distribution and SOC content of the aggregates. About 90% of aggregates were > 2 mmin natural Cerrados, but after 11 years of cultivation only 62% were in this size range. This change in aggregation shows that the slow SOC pool is also an important component of macro-aggregates. Further, disturbed systems contain low levels of SOC compared with undisturbed systems. Several other experiments have shown increase in total aggregation by application of organic amendments and compost (Tisdall, 1996). Aggregation is also improved by application of even a low level of polymers or soil conditioners (Williams et al., 1968; Greenland, 1972; Levy, 1996). Soil conditioners are mostly used in stabilizing soil structure and for erosion control on steep slopes. However, conditioners may also be used in improving aggregation for increasing SOC and C sequestration. Deep incorporation of humus or non-labile fraction beneath the plow layer is another effective strategy for C sequestration (Bouwman, 1990; Fisher et al., 1994). It has been understood carbon placed beneath the plow layer is not easily decomposed because it is not exposed to climatic elements. Practices that lead to deep placement of SOC include activity of soil fauna, vertical mulching, and growing deep-rooted annuals and perennials (Lal and Kang, 1982; Wilson, 1991). Vertical mulching is a technique of soil-water conservation whereby crop residues and other biomass are placed in trenches 30 to 50 cm deep. Deep placement of residues keeps trenches open and facilitates water infiltration into the soil. Vertical mulching, practiced regularly with substantial quantity of crop residue, can also facilitate increase in SOC in the sub-soil horizons (Lal, 1986). Growing deep-rooted plants is another useful and a practical technique of improving soil structure and increasing SOC content in the sub-soil horizons. Fisher et al. (1994) observed that growing improved pastures in acid savanna soils in South America may drastically improve SOC content of the sub-soil. In West Africa, Lal et al. (1978; 1979) also observed significant positive effects of growing cover crops on increase in SOC content.

Chivenge et al (2007) reported that developing viable conservation agriculture practices to optimize SOC contents and long-term agroecosystem sustainability should prioritize the maintenance of C inputs (e.g. residue retention) to coarse textured soils, but should focus on the reduction of SOC decomposition (e.g. through reduced tillage) in fine textured soils. Chivenge et al (2004) studied the long-term tillage effects on soil organic C and N distribution in particle size fractions of a chromic luvisol (FAO soil classification) soil profile. They reported that relative to the weedy fallow, conventional tillage showed a more marked decline in organic C and total N than mulch ripping. Rachid Mrabet (2002) reported that conservation tillage has the potential for increasing soil organic matter content and enhancing soil aggregation and can create an aggregated, fertile surface layer that is important from a soil erosion reduction perspective and thus for a sustainable agriculture in Africa. Elisée Ouédraogo (2006) has studied the effects of tillage, soil fauna and nitrogen fertilizer on soil carbon build-up on a Ferric Lixisol and a Eutric Cambiso in West Africa. He reported that soil carbon build-up requires judicious combination of low quality organic resources and nitrogen input in tilled systems. In no-till systems, high quality organic amendments favoured soil carbon buildup but soil and water conservation measures are needed to reduce organic matter and nitrogen losses. In this study, soil fauna played a key role in the decomposition of low quality organic materials and its incorporation into the soil. However, in nitrogen deficient soil, nitrogen input is needed to maintain soil organic carbon level. Based on this study, it has been concluded that soil carbon build-up in semi-arid West Africa is an art of balancing, taking into account nitrogen status of the soil, nitrogen inputs, the quality of organic amendments and soil tillage.

Effect of conservation agriculture management practices on crop response, organic carbon and soil quality improvement under Indian condition - Research experiences

There are several reports on the influence of conservation agricultural management practices comprising of tillage, residue recycling, application of organic manures, green manuring and integrated use of organic and inorganic sources of nutrients, soil water conservation treatments, integrated pest management, organic farming, etc., on soil quality. Improved soil quality parameters create additional muscle power to soil to combat the ill effects of climate change. Some of the results pertaining to the effect of conservation agricultural practices on soil quality are given below:

The studies conducted over a 9 year period in Alfisols at Bangalore with finger millet, revealed that the yields were similar with optimum N, P, K application and with 50% NPK applied through combined use of fertilizers + FYM applied @ 10 t ha^{-1}. Application of vermicompost in combination with inorganic fertilizer in 1:1 ratio in terms of N equivalence was found very effective in case of sunflower grown in Alfisol at Hyderabad (Neelaveni, 1998). Combined use of crop residues and inorganic fertilizer showed better performance than sole application of residue. Use of crop residue in soil poor in nitrogen (Bangalore) showed significant improvement in the fertility status and soil physical properties. Continuous addition of crop residues for five years enhanced maize grain yield by 25%. Organic matter status improved from 0.5% in the control plots to 0.9% in plots treated with maize residue at 4 t ha^{-1} $year^{-1}$. In Alfisols at Hyderabad, use of crop residues in pearl millet and cowpea not only enhanced the yields but also made appreciable improvements in stability of soil structure, soil aggregates and hydraulic conductivity.

Capitalisation of legume effect is one of the important strategies of tapping additional nitrogen through biological N fixation. There are many reports on this aspect (Singh and Das, 1984; Sharma and Das, 1992). The beneficial effect of preceding crops on the succeeding non-legume crops has been studied at many locations. When maize was grown after groundnut, a residual effect of equivalent to 15 kg N ha^{-1} was observed at ICRISAT (Reddy et al. 1982). Sole cowpea has been reported to exhibit a residual effect of the magnitude of 25-50 kg N ha^{-1} (Reddy et al. 1982). Based on a five year rotation of castor with sorghum + pigeon pea and green gram + pigeon pea in an Alfisol of Hyderabad, it was observed that green gram + pigeon pea intercrop (4:1) can leave a net positive balance of 97 kg ha^{-1} total N in soil (Das et al. 1990).

Based on the results of a long term experiment conducted in Cotton based system in Vertisols at Akola, organic C in soils varied from 5.72 g kg^{-1} (control) to 7.32 g kg^{-1} in 25 kg P_2O_5 ha^{-1} + 50 kg N ha^{-1} through leuceana followed by 25 kg N (Fert) + 25 kg P_2O_5 ha^{-1} +25 kg N ha^{-1} through FYM (7.24 g kg^{-1}), thus registered an increase of about 28 % and 26.6 % increase in organic Cover control over a period of 19 years (Fig 1) (Sharma et al 2011). Similarly, residue application and graded N levels for seven year exhibited a significant increase in organic carbon content in rainfed Alfisol in case of castor - sorghum rotation irrespective of the tillage levels. However, no significant difference in organic was observed between conventional and minimum tillage (Sharma et al., 2005).

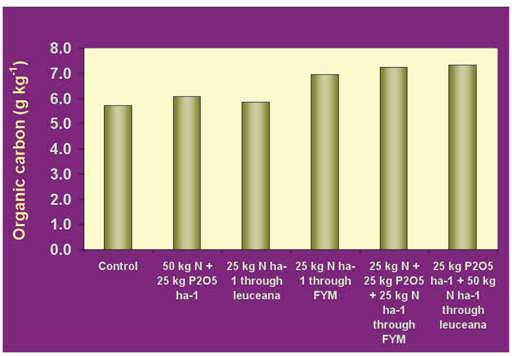

Fig. 1. Effect of different long-term nutrient management treatments on organic carbon content under cotton + green gram intercropping system in Vertisols at Akola.