International Conference
on
Sustainable Natural Resource Management under Global Climate Change

November 07-10, 2023
New Delhi, India

BOOK OF INVITED PAPERS

Organized by

Soil Conservation Society of India, New Delhi

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PREFACE

Climate change is reality which has now globally accepted and has a significant impact on agriculture and its allied sectors.In addition to climate change, the increased frequency of extreme events, such as droughts and floods, poses a greater challenge for farmers and researchers and threatens food security. With an increasing human population coupled with climate change, virtually all of our natural resources have been put under more stress than ever, causing them to become scarcer and more expensive to source in the future. According to FAO estimates, meeting 60% of the additional food demand by 2050 will be challenging due to the depletion of natural resources. The warmer water temperatures are likely responsible for causing a shift in the habitat ranges of several fish and shellfish species and potentially disrupting the ecological balance of aquatic ecosystems. Moreover, the increased temperature disturbs the distribution and composition of tree species and the species variation proceeds in the forest ecosystem. The overall result of climate change is that farming crops and raising animals and fish will no longer be as easy as it used to be. The impact of climate change will be severe in almost all countries. However, the small and marginal farmers of developing nations are in jeopardy. Hence, technology-driven mitigation and adaptation measures for natural resources management are indispensable. Therefore, establishing an interface between academicians, researchers, government departments, policymakers, farmers, industry, and other stakeholders is crucial for a blueprint for sustainable natural resource management under climate change scenarios.

In light of the emerging new challenges, the Soil Conservation Society of India, New Delhi is organizing its 5th International Conference on "Sustainable Natural Resource Management under Global Climate Change" at the National Agricultural Science Centre (NASC), ICAR, New Delhi, India during November 7-10, 2023. The International conference is organized in collaboration with ICAR - Indian Agricultural Research Institute, New Delhi, National Academy of Agricultural Sciences (NAAS), India, International Soil Conservation Organization, World Association for Soil and Water Conservation, China, International Union of Soil Science, Austria and European Society for Soil Conservation.

Learning and sharing the knowledge from the global community is becoming the order of the day due to the complexities in addressing the issues and the greater need for innovative and robust solutions to achieve short, medium and long-term goals in sustainable natural resource management. This International Conference would provide an opportunity for the confluence of ideals, practices and visions of stakeholders i.e. scientists, researchers, development agencies, policymakers, private sectors, NGOs and students from the international level. This will be a platform for global discussions and deliberations on this worldwide issue and for deriving evidence-based strategies for implementation.

For 5th International Conference of SCSI 2023, lead papers were invited worldwide in 10 major themes viz., Natural Resource Management towards achieving Sustainable Development Goals (SDGs), Scientific tools for land resource inventory, hydrologic assessment and decision support systems for effective management of natural resources, Vulnerability, resilience and mitigation of climate change impact on water resources systems, Sustainable management of Groundwater, Planning of efficient Soil and Water management, Hydrology and digital application for management of Watersheds, Ecosystem and their valuation including Biodiversity conservation and management, Mitigation of climate change impact on soil health and carbon sequestration, Climate change adaptation in agriculture and allied sectors, and applications of jute geotextiles for natural resource management. Invited papers were compiled and published as Book of Invited Papers.

We place on record our gratitude to Dr Himanshu Pathak, Secretary (DARE) and Director General (ICAR) for his guidance and support extended in all aspects to organize this conference. We express our deep gratitude to Dr. A. K. Singh, Director & Vice Chancellor, ICAR – IARI, New Delhi for permitting us to organize the conference and extending all support for bringing out this publication. We are grateful to Dr Anil Kumar, ADG (Coordination), ICAR for his constant support to organize this conference. We are thankful to Late Dr. SurajBhan, former President, SCSI and Dr TBS Rajput, President, SCSI for guiding us in every moment of organizing the event and bringing out this publication. We sincerely thank all authors who contributed their valuable findings to this publication.

We greatly acknowledge the financial support extended by the Indian Council of Agricultural Research, India; Ministry of Jal Sakthi, Government of India; Department of Land Resources, Government of India; National Jute Board, Kolkata; National Rainfed Area Authority (NRAA); Indian Oil Corporation Limited; Council of Scientific & Industrial Research (CSIR); National Biodiversity Authority (NBA) and Gas Authority of India Ltd. Conference facilities provided by National Academy of Agricultural Sciences (NAAS) for conducting this event is highly acknowledged..

The financial assistance received from the Research and Development Fund of the National Bank for Agriculture and Rural Development (NABARD) towards the publication of this Book of invited papers of the International Conference is gratefully acknowledged. The editors also express our sincere thanks to all the co-sponsors and advertisers for their financial support.

We hope this Book of Invited Papers will provide all stakeholders with detailed information on sustainable natural resource management technologies, enabling them to make necessary research and development activities to combat global climate change.

EDITORS

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Sustainable Water Management and Climate Smart Agriculture for Livelihood and Food Security in India

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Introduction

Agriculture in India is transforming in a faster rate. The strategy of grow more at any cost has been converted to sustainability in production. Climate change is generally emerging as a major threat to farm production and it induces forceful changes in rhythm of agricultural practices and thereby disturb the crop calendar. Water, being the most important input in farming either became scarce or excess necessitating drainage during critical crop seasons and subsequently leading to crop loss. Not only water, the function of most of the actors along the supply chain is related to the climate change. Apart from climate change, many factors such as the changes in land use pattern, availability of farm laborer, demography, migration, soil fertility, policies etc. affect the agricultural production and productivity. Increasing emission of greenhouse gases from agriculture and animal farming raise concerns. However, all these constraints can be managed in a better way using advanced technological solutions, tools and platforms.

Technology driven Smart Management of Agriculture

When talking about modern farming technology, we have to acknowledge the role of information and communication tools and advanced IT platforms as a decision support system for farmers. Artificial intelligence, analytics, connected sensors, geo-spatial products and other emerging technologies could further increase yields, improve the efficiency of water and other inputs, and build sustainability and resilience across agriculture.

Modern information tools have largely revolutionized the way people, governments, and businesses function in the modern world. Close to 60% of the global population has access to the internet, and mobile phone is now the most widely-used channel for internet access worldwide. This transition has facilitated better communication and ensured the delivery of services and information to people who previously lacked access. If connectivity is implemented successfully in agriculture, the industry could have $500 billion in additional value to the global gross domestic product by 2030 (Goedde et.al, 2020).

The infusion of new, advanced agriculture technologies has allowed the global agriculture sector to surge ahead and transform the way the producers cultivate, harvest, and distribute agricultural commodities. Smart agriculture with the use of advanced IT tools and platforms can be applied anywhere and at any time along the value chain (Fig. 1). It makes the process much simpler as well as faster and ensures better quality of the end product while assuring better price to the producers. The use of technology in Indian agriculture has particularly revolutionized smallholder agriculture and has helped to address several challenges associated with the traditional form of agriculture.

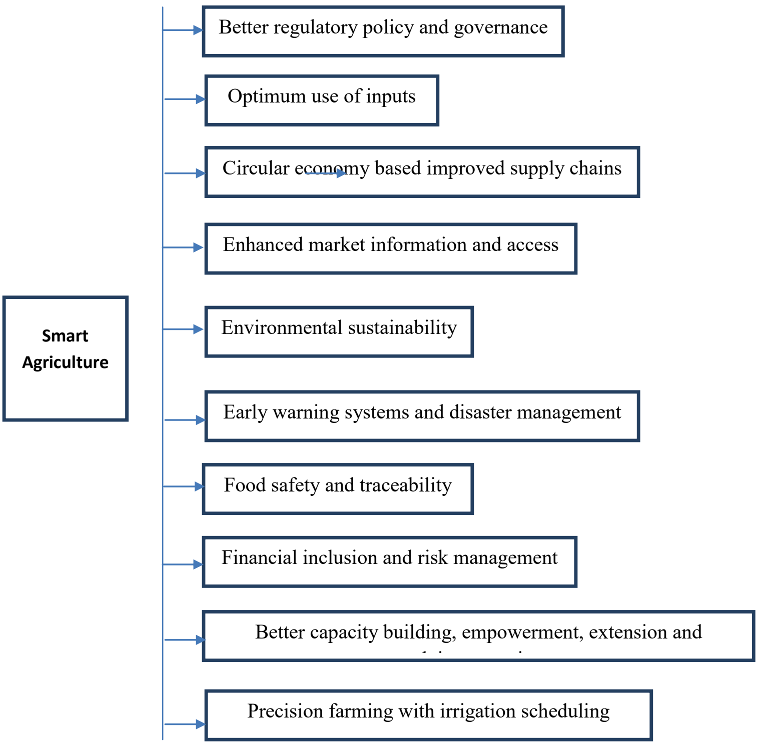

Fig. 1: Smart Agriculture Avenues

The agricultural scenario today requires the integration of sophisticated technologies such as temperature and moisture sensors, robots, GPS technology, and aerial images and geo-spatial data, hyper spectral sensing and many more. Such digital farming technologies help the rural farmers towards accessing effective production strategies, banking and financial services, and real time market information.

In many countries, ICT in agriculture provides farmers with vital information pertaining to sowing, crop protection, and improving soil fertility that enables them to improve agricultural productivity. Weather-related advisories and alerts help them prepare for sporadic events such as floods, drought, or even pest and disease outbreaks, thus preventing significant crop loss. The Water Resources Information System portal developed by State agencies provides dynamic details of weather, surface water, groundwater, reservoir operations, canal flow, soil moisture, water quality and all other relevant and required information on water in the respective States.

The use of ICT in modern agriculture technology has also significantly transformed agriculture and farming in developed countries at a different scale. Internet of Things (IoT), Cloud Computing, ML, Deep learning, Hierarchical systems and Big Data have all had a profound impact on the efficiency of current processes. Several farmers in US and Europe manage their farms remotely using sensing technologies, drones, and other devices that gather vital data on soil properties, air, crop health, and weather conditions.

FATIMA (FArming Tools for external nutrient Inputs and water MAnagement) is one of the joint research efforts which used the earth observation data in order to monitor and manage the agricultural resources in a more effective and efficient way. The project was funded by the European Commission under the Horizon 2020 programme of research and innovation. It is a multi-national project with 9 active participating countries. In the project, satellite data from Landsat-8 and Sentinel-2 sources were used to monitor pilot plots where various crops have been traditionally cultivated. In the process of 3 years in the project, each harvest provided new outputs about forecasting crop water requirements (CWR) and crop yield variability (Cordis, 2023). OpenETplatformavaliable in western states of USA provide easily accessible satellite-based estimates of evapotranspiration (ET) for improved water management across the western United States. Browsing the website openetdata.org, users can explore ET data at the field scale for millions of individual fields or at the original quarter-acre resolution of the satellite data (Melton et al., 2021).

All available spatial, temporal and physical data should be scouted, processed and analyzed in such a way that some user-friendly products and deliverable are developed and made available to the farmers. These products can be in the form of a DSS, expert system, Mobile App, Web based tool, url, GuI or anything. It should ultimately enable the farmers and agribusinesses to closely monitor the crop cultivation inputs and practices, optimize the use of agrochemicals and natural resources, and adapt quickly to changing environmental conditions.

IoT, in particular, has several applications in agriculture, from real-time monitoring of soil, plant, and animal health using in-situ sensors to tracking the origin of a product or agri-commodity and its environmental impact, as well as its storage environments along the supply chain. In near future sensors and machines will be developed, based on in-built AI and data analytics capacity, which is capable of self-optimizing and initiating activities on their own, without much human intervention. The self-managed precision farming systems with Agrobotscan revolutionize the future farming.

India's water woes and opportunities

The total utilizable water resources in India including both surface and groundwater resources is 1123 BCM and country's average annual demand is about 840 BCM (Gupta and

Deshpande, 2004). However, the projections show an increase in demand to the tune of 1200 BCM by 2050 and this may lead to water crisis (CWC, 2012). The demand-supply paradigm of water in India shows the trend of narrowing the gap between the supply and demand with shrinking supply with increasing demand. Though half of the agricultural area is rainfed and without access to irrigation, the sector uses close to 90% of the total water used in the country. Further, the groundwater table show small to very high decline in 36% of the blocks mainly due to water withdrawal exceeding water recharge (Chand, 2022). In the irrigated agriculture sector conventional irrigation practices prevail. Overall efficiency of Canal Distribution Network in India is only about 35-50% (Madhok, 2020) and there is ample scope for improve the water distribution and use efficiency so that the total water demand in the country can be brought down.

Marginal increase in supply is possible by means of rainwater harvesting, reuse and recycling of grey water etc., but it may not be in match with the rapid increase in water demand by different sectors, including agriculture, drinking/domestic, industrial, recreational/ tourism, inland fisheries etc.

Improving water use efficiency or enhancing agricultural water productivity is a critical response to growing water scarcity, including the need to leave enough water in rivers and lakes to sustain ecosystems and to meet the growing demands of cities and industries (Drechsel et.al., 2015). Agricultural water productivity is the ratio of the net benefits from crop, forestry, fishery, livestock and mixed agricultural systems to the amount of water used to produce those benefits (Molden and Oweis, 2007). The agricultural water productivity can be improved by means of reducing losses while diverting, distributing and applying water to the crops. Adaption of modern tools and technologies for scheduling and optimizing water application is also important.

Managing land and water- Novel approaches

Land and water are among the most important of all natural resources, hence maintaining these resources are essential for sustainable development specially to sustain the agricultural productivity. Land and water are vital resources in urban, agricultural, and natural ecosystems.

The availability of water has become unpredictable with the disruption in weather pattern due to climate change. Proper understanding and modelling of climate variability are essential for efficient and sustainable utilization of water resources. Under rapidly changing environment, sustainable water management through targeted research on each sphere of soil: plant: water continuum is essential and to increase food production through enhancing water productivity, identifying adaptation needs and addressing the challenges and research directions in water management in humid tropics are of great importance.

The productivity of most of the crops is low in many parts of the country, when compared to the national average. Lack of irrigation and low fertile lateritic soils are some of the important factors contributing to this low productivity. These are coupled with the serious unresolved problems such as high labour charges and high cost of cultivation and due to this, the farming community is in a deplorable plight. The country faces the challenges of both increasing farm productivity and increasing sustainability and resilience to climate change. Effective government intervention based on modern tools and technologies, with people's participation is the need of the hour to save the grave crisis faced by farmers.

One of the major factors which affect the production and productivity of agricultural crops is crop water management. In view of increasing water demand and shrinking supply, the only way to ensure sustainable agricultural production is to enhance the water use efficiency.

The efficiency of conventional irrigation systems is less and hence there is a need for greater awareness among the farming community to adopt new practices including micro-irrigation systems. Institutional innovations coupled with novel practices and technologies in irrigation sector is the need of the hour. The water conveyance, distribution and application efficiencies in traditional systems of irrigation are also to be improved. Community management of water resources, participatory irrigation systems, recycling of grey water for irrigation, pollution management of water resources etc. are also vital for productivity enhancement of crops. New approaches and technologies like water budgeting of major crops in various agro-climatic-ecological zones, AI/ML/Sensor based irrigation scheduling, automated irrigation, conjunctive use of surface and groundwater, climate smart irrigation, and drought proofing models are to be linked to the irrigation planning and operations.

Community-based micro-irrigation systems can be introduced to agricultural areas that were earlier under rainfed agriculture and faced crop failures due to scanty rainfall. The introduction of micro-irrigation systems would help to bring down pressure on groundwater resources, enhance the yield and quality of the produce and reduce the farm energy and fuel consumption, leading to considerable reduction in Green House Gas emissions.

Smart agricultural Solutions- Examples:

(i) GramWorkx ET based Irrigation scheduling company: GramworkX is an IoT and AI-enabled smart farm resource management platform that helps farmers to reduce pest-related risks, improve irrigation efficiency and optimize the agricultural inputs. It provides farmers with micro-climatic conditions of their farms, real time weather insights, future weather predictions, but also helps in future irrigation planning and day to day activities.This system helps farmers and farming organizations they can take accurate, proactive, preventive decisions. The GramWorkx analyses data from field installed automatic weather stations and soil sensors with the help of a customized algorithm and take appropriate decisions on application of agricultural inputs including water, nutrients and pesticides/insecticides etc. The field operations including irrrigation can be managed through automated and AI driven systems.

(ii) AgNext: AgNext has innovated & developed full-stack integrated algorithms, software & hardware platform, which addresses quality assessment issues across the agri value chain, enabling businesses to analyse food on-the-spot in just 30 seconds.This integrated platform can undertake objective portable quality assessments, analyzing food in 30 secs, instant and on-edge. This innovative startup is using new-age technologies benefitting various stakeholders of agriculture and food value chains improving post-harvest trade by bringing transparency & trust.

(iii) Upajj: Upajj is an online B2B marketplace with a simple goal - to leverage innovative technology that would make the lives of farmers more efficient, more profitable and more sustainable. It gives advices on optimization of farm inputs including water and nutrients with the help of hyperspectral images and filed sensors. It will also provide expert advisory services to the farmers on crop production and protection aspects.

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Eco-friendly and Climate Resilient Water Management Interventions

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Introduction

Climate induced natural disasters pose severe threat to national food security in India. The diminishing water resources in agriculture coupled with ever increasing human population further intensifies the challenge to achieve food security in India. Though the food grain production of India was pegged at 331 M ha during 2022-23, the fulfilment of projected target during 2050 would be a challenging task in the context of declining water resources. Extreme climatic events have been witnessed at higher frequency now. This necessitates us to minimize the damage to agricultural sector in the backdrop of changed climate and to develop or enhance climatic resilience. We need to promote adaptive capacities and the mitigation of climate change and work towards disaster risk reduction. Eco-friendly and climate smart agriculture (CSA) is the solution for this scenario.As per the Food and Agricultural Organization of the United Nations (FAO),CSA may be defined as "agriculture which aims at sustainably increasing productivity, enhancing resilience (adaptation) and reducing/removing greenhouse gas emissions (mitigation) which in turn would facilitate achievement of national food security and development goals" (FAO 2013). Resilient agricultural system may be defined as a combination of different agricultural practices that provide better resistance and adaptability to different crops when exposed to various natural disasters such as floods and drought.

Water is one of the key inputs for agricultural productivity and its timely and adequate supply is directly proportionate with the economic produce. However, its supply / availability is negatively influenced due to climate change. Owing to extreme events, the crops are subjected to either excess water stress or deficit water stress (Brahmanand*et al.,* 2013). In terms of magnitude, drought events are on increasing trend and we have to plan for integrated water resource management plan for combating the negative effects of climate change. As water is becoming a limiting factor for crop production, soil and water management should be the key to the development of eco-friendly and climate smart agriculture for both irrigated as well as rainfed areas. The rainfed ecosystems contribute about 58% of world cereal production and hence water management in these areas is essential for sustaining the food production. This holds more relevance in view of shrinking per capita land and water resources under the backdrop of climate change. This necessitates us to critically analyze the existing water resources of India, sector wise water demand and prioritization and wide scale adoption of eco-friendly climate resilient water management techniques and integrating them in to water management policy interventions or schemes such as Pradhan Mantri Krishi Sinchayee Yojana (PMKSY).

Water resources scenario in India

Owing to increasing demand of water for sectors like domestic, industrial and energy, there is a severe constraint in the availability of water for irrigation sector / farming. It has been assessed that the utilizable water is 1123 BCM (690 BCM from surface 433 BCM ground water) only, which accounts to about 28% of the water derived from precipitation. Annual groundwater recharge is about 433 BCM, of which 212.5 BCM is used for irrigation. Out of net sown area of about 139.9Million ha, the net irrigated area in India as on 2013-14 is 75.5Million ha (54% of net sown area). The remaining 64.4Million ha area is under rainfed condition (46% of net sown area). The area irrigated through other sources is 7.54 million ha. Similarly, the gross irrigated area of the country is 112.2Million ha accounting for 53% of the gross cropped area (211.4 M ha).

The 2030 Water Resources Group assesses that about half of the demand for water will be unmet by 2030 if the current pattern of demand continues. The availability of water for agriculture in India is expected to decline from 84% in 2010 to 74% by 2050. Even within agriculture, the water demand for different subsectors or farming systems will change significantly in the coming years. The enhanced water demand in domestic, industrial and energy sectors will need additional 222 BCM water by 2050 (Table 1).

Low water use efficiency and poor maintenance of irrigation systems are some of the major problems while managing the water resources in the country. The evergrowing Indian population necessitates us to enhance the foodgrain production at significant rate which will put tremendous pressure on the existing water sources. This challenge can be met by enhancing irrigation efficiency and water productivity under eco-friendly and

Table 1: Sector wise projected water demand in India

(billion cubic meters)

Sector/Year	**2000**	**2010**	**2025**	**2050**
Irrigation	541	688	910	1072
Domestic	42	56	73	102
Industry	8	12	23	63
Energy	2	5	15	130
Others	41	52	72	80
Total	634	813	1093	1447

(Source: Central Water Commission, 2010) climate smart agriculture. Keeping these points in view, there is a strong need to focus on eco-friendly climate resilient water management techniques and crop diversification with priority on low water requiring crops like millets. Some selected promising interventions are described here.

Eco-friendly climate resilient innovative water management interventions

Solar-powered soil moisture sensor-based automatic surface irrigation system

Soil moisture sensor-based automatic surface irrigation system developed by Water Technology Centre, ICAR-Indian Agricultural Research Institute, New Delhi is another breakthrough crop production technology which enhances the water application efficiency of surface irrigation system (Pramanik et al., 2022). This system consists of an automatic check gate, soil moisture sensors, a communication system, and a web/mobile interface. The check gate is made of an aluminium sheet attached to an iron frame installed in the field inlet channel. The solar-powered capacitance soil moisture sensor installed in the field senses the real-time data and transmits it to the cloud server via the gateway. The wireless communication was established with LoRa and GSM modules. The cloud server is wirelessly connected to the check gate and mobile or web interface though GSM module. Farmers can download the mobile app from Google Play. The real-time soil moisture status can be monitored on mobile by the user/farmer and the system enables the farmers to start (open check gate) and off (close the check gate) the irrigation based on real-time soil moisture status from anywhere/remotely. The irrigation scheduling with an automatic real-time soil moisture-based system helped to save nearly 25% of water as compared to the conventional method of irrigation. It also helped to enhance water use efficiency and water productivity by 30% as compared to conventional practice. It is also recommended that a minimum of two soil moisture sensors per unit area should be installed in the field i.e. one for opening the check gate and another for closing the check gate. The placement of the sensor should be 50% of the field length at 15 cm depth for opening the check gate and closing the check gate, placement depends upon the crop type (shallow/deep-rooted). If the crop is shallow rooted then the second sensor should be located

Solar-powered soil moisture sensor-based automatic surface irrigation system

at 75% of the field length and 7.5 cm depth and if deep a rooted crop, then it should be located at 25% of the field length at 37.5 cm depth. The automatic surface irrigation system has the potential to make a significant contribution in water, labor and energy saving in agriculture sector.

Design of tank cum well system in watersheds in rainfed areas

The tank cum well system technology along the drainage line in a watershed is recommended for plateau areas having slope of 2 to 5% (Roy Chowdhury *et al.*, 2016). The site for the technology should be selected in such a way that the area should have a well-defined valley where the runoff flows either as overland flow or channel flow. The well is constructed about 100 to 300 m downstream of the tank to tap the water that is lost by seepage from the tank. A set of 15 tanks and wells is required for a catchment area of 500 ha to irrigate 60 ha area. The technology has a potential to generate Rs. 30,000/- extra gross income per year with additional employment generation of 115 man days per ha. It can increase the cropping intensity to up to 166%.

Conservation agricultural practices for better drought resilience

In-situ moisture conservation measures such as zero tillage, mulching and residue incorporation play vital role in drought management. Zero tillage was found to enhance the economic yield of crops such as okra, sunflower and bittergourd up to 15% compared to conventional tillage in addition to significant moisture saving. Similarly, the creation of secondary (auxiliary reservoir) also has a vital role in enhancing the cropping intensity, crop productivity and net returns of the farmers in drought prone minor irrigation commands (Mishra *et al.,* 2013).

ICAR-flexi rubber dams for watersheds

The installation of rubberdams in watersheds act as better drought resilience structure and it will significantly help in additional water storage, crop productivity and net economic returns to the farmers (Jena and Brahmanand, 2014). This technology developed by ICAR-Indian Institute of Water Management, Bhubaneswar has potential to create an additional water storage capacity of about 52,000 to 80,000m^3 for irrigating about 30-40 ha of paddy in kharif and 6 ha of pulses, oilseeds and vegetable crops in rabi season. In rubber dam command the productivity of rice in kharif season enhanced up to 62% and in rabi season productivity of vegetables increased up to 47% due to installation of rubber dams in watersheds. It has potential to enhance the net returns of the farmers up to Rs.48,000/ha.

Over-aged rice seedlings and flood resistant / tolerant rice varieties

ICAR-Indian Institute of Water Management, Bhubaneswar developed a flood resilient mechanism in the form of over aged seedlings of 60 days old which has provided an yield advantage of about 32% over the normal seedlings (30 days old) and most importantly this practice has helped successful establishment of seedlings in flood prone areas (Roy Chowdhury *et al.*, 2011).Flash floods are frequently witnessed due to heavy rains with in short period resulting in huge crop loss. The flash flood tolerant rice varieties such as Swarna Sub-1 should be used by the farmers to reduce the yield loss under such conditions.

Contingency crop planning and post flood management

About 40 million ha of land in India is prone to diversified nature of flood events i.e. flash floods (due to heavy downpour within a short period, river floods (due to continuous rain or snow fall in catchment region) and coastal floods (due to storm surges as a result of tropical cyclones) (Brahmanand*et al.,* 2017). Under such scenario, contingency crop planning and post-flood management plays vital role in providing cushion to the farmers in flood affected regions.Post-flood management (PFM) refers to the collective crop management decisions taken by the farmers and other stakeholders in the agricultural sector to establish the alternate crops and to provide better resilience to the existing crops after the occurrence of flood event. The farmers will be well prepared to implement the package of practices needed for successful establishment and higher crop productivity. This would minimize the yield reduction under the event of flood disaster. This holds higher relevance as the nature and extent of flood varies at both temporal and spatial scale and we need to dynamically plan and implement post-flood management interventions.The post-flood management plan (cultivation of wheat, mustard, lentil, maize, brinjal, tomato, cucumber and cauliflower) implemented in Muzaffarpur district of Bihar resulted in higher crop resilience and crop productivity thereby resulting in additional net economic returns upto Rs. 29,800/- per ha and Rs. 32,400/- per ha compared to flood damaged field without intervention during 2019-2020 and 2020-21 respectively. The farmers were also encouraged to cultivate mango saplings in agricultural fields for better cushioning during flood event. Overall, the post-flood management interventions resulted in enhancement of benefit:cost ratio from 1.55 to 3.08 and have potential to enhance agricultural resilience in chronologically flood prone areas of India (ICAR, 2020). Most of the beneficiaries of post-flood management interventions were also enrolled under the index-based flood insurance project. About363enrolled farmers in flood affected regions of Bihar were paid crop insurance based on the flood damage index developed by researchers of ICAR-IWMI collaborative project. It is pertinent to mention here that the farmers used the payout money on agricultural activity like purchase of seed, fertilizer, irrigation etc.

Bio-drainage options for better flood resilience

In flood prone and waterlogged areas, the practice of bio-drainage using *Casuarina and Eucalyptus* plantations would act as a viable flood resilient system as they improve soil drainage and operates better micro climate. This allows intercrop cultivation and helps in advanced planting of rabi crop resulting in higher water and land productivity.

Drone-based Water Stress Monitoring

Huge scope exists for drone-based irrigation monitoring and identification of variable plant stress zones in India. The application of drones is more significant in identification of mechanical problems in canal operation and maintenance which may lead to sustainable water resource development. The prospects for use of drones in agricultural sector in India will be improved with the new regulations issued by Government of India. We also need to encourage public-private partnership in promoting precision irrigation system as some of the private companies like Tata Kisan Kendra have marched ahead in providing digital farming solutions to farmers in precision farming and precision irrigation system (Brahmanand and Singh, 2022).

Crop diversification with priority on millets based on water resource availability

Being low water consuming crops, millets alongwith pulses and oil seeds fit well under crop diversification from water guzzling crops like rice and sugarcane. Millets add towards diversification of predominant cereal-based rice-wheat and maize-wheat cropping systems. Moreover, the inclusion of millets can play vital role in ensuring nutritional security of India. With the launch of schemes by Government of India for promotion of millets and their value addition, it is expected that the small and marginal farmers will be able to enhance their net economic returns.The major millet growing states of India are classified in to two categories i.e. High productivity States and low productivity states based on the All India mean productivity of total millets (1302 kg/ha). Eight States Andhra Pradesh, Gujarat, Haryana etc are categorized as High productivity States (Table 2). Similarly, seven Indian States like Karnataka, Arunachal Pradesh, Rajasthan etc. come under Low productivity States.

The water management strategies need to be different based on the status of water resource availability and water demand of major millet growing states. The states like Odisha where water resource availability exceeds water demand are classified as surplus water category. The states where water demand exceeds water resource availability are classified as deficit water category. Further, the states where water demand exceeds water resource availability by more than 50% are categorised as Severe water deficit states. The micro irrigation needs to be prioritised for millets in case of severe water deficit states like Rajasthan.

Further, we need to devise the water management strategies based on the classification of these regions to four categories:

1. High productivity and surplus water resources
2. High productivity and deficit water resources
3. Low productivity and surpluswater resources
4. Low productivity and deficit water resources

Table 2: Productivity based Classification of major millet growing States of India

High Productivity Zone (>1301 kg/ha)	Low Productivity Zone (<1301 kg/ha)	All India Productivity (kg/ha)
Andhra Pradesh	Karnataka	1302
Gujarat	Arunachal Pradesh	
Haryana	Rajasthan	
Madhya Pradesh	Maharashtra	
Uttar Pradesh	Jharkhand	
Telangana	Odisha	
Uttarakhand	Chhattisgarh	
Tamil Nadu		

The emphasis should be given to water and nutrient use efficient practices, rainwater conservation, water distribution network and horizontal expansion of millets in case of 'High Productivity and SurplusWater Resources'. The In-situ soil moisture conservation practices, water use efficient practices, creation of new RWH, optimal cropping pattern and conjunctive use of surface and ground water resources need to be concentrated in regions with 'High Productivity and DeficitWater Resources'. In case of regions with 'Low Productivity and SurplusWater Resources', emphasis may be given to water distribution network, optimal irrigation scheduling, micro irrigation and water quality monitoring and management. Similarly, for regions with 'Low Productivity and DeficitWater Resources', the priority may be given to creation of new RWH, rain water conservation, optimal cropping pattern, irrigation at critical crop growth stages and in-situ soil moisture conservation practices.Overall, we need to promote the cultivation of millets through phase wise crop diversification in the potential districts / blocks of Indian states. At the same time, we need to enhance the area under irrigation for sorghum (from existing 11.1%) and pearlmillet (from existing 15.2%) to atleast 25% for enhancing the productivity of these crops (DAF&W, 2023).

Conclusion

The vulnerability of different agro-ecosystems has been found to be on increasing trend due to the higher frequency and magnitude of extreme climatic risks or events in the recent years. This challenges the national food security objectives by affecting the crop production resulted by excess water stress or deficit water stress. Hence, the efforts must be concentrated on evolving eco-friendly and climate resilient agriculturalpractices through best utilization of created water resources and adoption of innovative water management practices leading to higher water use efficiency and water productivity. Upscaling of the proven innovative water management techniques suitable for climate induced excess and deficit water stress scenarios would certainly make agriculture more viable economically thereby providing better cushion to the farming community. At the same time, we need to emphasize on phase wise crop diversification with priority on millets based on precipitation and water resource availability.

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Soil Fertility and Health Management for C Sequestration and Sustainable Agricultural Production

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Introduction

Poor land and soil management practices are associated with widespread severe degradation in global agricultural systems. Urgent attention to judicious land use and prudent soil/crop/water management is required to restore degraded soils and improve the environment (Lal 2019a). Maintaining or enhancing the SOC stocks is one of the most critical interventions to fight against climate change, soil degradation and ensuring the sustainability of agriculture. The global soil organic carbon (SOC) stocks are 677 Pg to 0.3 m, 993 Pg to 0.5 m and 1,505 Pg to 1 m depth. It is evident that about 55% of the SOC is restrained to the top 1 m soil depth is below 0.3 m depth. However, the average SOC stocks are relatively lower in agroecosystems than in natural ecosystems due to lower biomass production, biomass removal/harvest, and land management practices such as tillage that increase the loss of SOC. The low carbon stocks place croplands as high priority areas for SOC sequestration. Although the goal of sequestering C in croplands appears straightforward, it faces several challenges and trade offs that need to be considered. This report aims to review and synthesize the current scientific evidence on the potential of various crop, soil and nutrient management practices to enhance soil C sequestration in different regions. This report highlighted the need for more research to provide policy-makers and farmers with the evidence base that will encourage them to adopt SOC-enhancing practices. Current evidence is clear that a site-specific nutrient management using a combination of mineral and organic fertilizers, combined with other techniques, can deliver optimal results for farmers and for food security.

Soil organic carbon (SOC) has been recognized as a critical indicator of soil health, because it reflects the level of soil functionality associated with soil structure, hydraulic properties, and microbial activity, thereby integrating physical, chemical and biological health of soil. Recently, increasing attention has been placed on SOC beyond the traditional sphere of soil science. This is because it is a key component of Earth's carbon cycle, thus having huge implications for the current climate crisis and SDG13: Climate action. Soil is the largest terrestrial carbon pool, holding an estimated 1500–2400 GtC and permafrost (i.e. frozen soil) storing 1700 GtC . A global initiative known as '4 per 1000', which aims to increase soil organic carbon by 0.4% per year, would result in an additional carbon storage of 1.2

GtC per year if successful (Paustian et al., 2016; Organic fertilizer applications can improve soil functionality and significantly increase SOC levels. Thus, applying organic amendments, including biosolids and composts, to agricultural land can increase carbon storage and contribute significantly to offsetting GHG emissions.

Issues and Challenges

Today's global population (7.2 billion) is expected to be around 8 billion by 2030 and 9.2 billion by 2050 (GOS, 2011). Most of these increases will happen in sub-Saharan Africa and Asia including India. India's population is likely to reach 1.5 billion by 2030 and 1.8 billion by 2050 (Swaminathan, 2009). Therefore, India's cereal production has to be doubled by 2050 in order to meet demand. Similarly, the demand of feeds for livestock and poultry and biofuel production increases. As cereal products are increasingly used as feed for livestock, which is estimated to be 45–50% by 2050 if meat consumption increases (FAO, 2003; 2006), finding alternative feed sources are essential for increasing the availability of cereals for human consumption. This poses a big challenge, since most of the easily available feed sources have already been fully exploited, although some alternatives still exist.

Without innovations and critical interventions, the global food production system will continue to degrade the environment, the biodiversity and eventually the world's carrying capacity. The widespread problems associated with the on-going intensification are topsoil erosion, depletion of soil fertility, soil acidification and salinization. In addition to other forms of degradation, the rates of excessive water extraction for irrigation which in many places exceeds the rates of replenishment, and heavy dependence on fossil fuel energy for synthesis of fertilisers and pesticides caused severe damages to the ecosystem (GOS, 2011). For example, the production of nitrogen fertilisers is highly energy intensive: the roughly fivefold increase in fertiliser price between 2005 and 2008 was strongly influenced by the soaring oil price during this period.

The Dilemma

The real dilemma is that the existing food system depends extensively on non-renewable resources and consumes at rates far exceeding their replenishment. On the other hand, all such practices release greenhouse gases, nitrates and other contaminants into the environment. Unless the footprint of food system on the environment is reduced, the capacity of the earth to produce food for all will be compromised with grave implications for food security in near future. Sustainability need for all sectors of the food system, from production to consumption, and in education, governance and research must be addressed properly. One of the daunting tasks is to fulfil the demand of the society by 2050 without degrading the natural resources (Foley et al., 2011). Converting these challenges to opportunities is the key for self-reliance what India is aiming at.

Soil Fertility Management

Nutrient management is essential to increase crop yield. There is a strong relationship between crop yields and the amount of SOC accumulation in the root zone. It is estimated that for each tonne of C sequestration, nearly 83 kg N, 20 kg P and 15 kg k is needed (Lal, 2004). Several studies in tropical regions of India have documented a positive relationship between SOC concentration in the root zone and yield of a number of crops including wheat, rice, and maize. For example, in alluvial soils of north India, wheat grain yield without fertilizer application increased from 1.4 Mg ha^{-1} at an SOC concentration of 0.2% to 3.5 Mg ha^{-1} in soils with an SOC concentration of 0.9%. With the application of chemical fertilizers the effect of SOC concentration, on wheat productivity was smaller indicating an interaction between SOC and fertilizer use. Judicious nutrient management is crucial to soil organic C (SOC) sequestration in tropical soils (Mandal et al., 2007). Adequate supply of nutrients in soil can enhance biomass production and SOC content (Van Kessel and Hartley, 2000). Use of organic manure and compost enhances the SOC pool more than application of the same amount of nutrients as inorganic fertilizers (Gregorich et al., 2001). Long-term manure application increases the SOC pool (Gilley and Risse, 2000), which not only sequester CO_2 but also enhances productivity of soil (Swarup et al., 2000; Manna et al., 2005). It is, however, argued that SOC sequestration is a major challenge in soils of the tropics and sub-tropics, where climate is harsh and resource-poor farmers cannot afford the input of organic manure and crop residues. The rate of C mineralization is high in the tropics because of high temperature and the humification efficiency is also low (Ladha et al.,2003). Integrated nutrient management involving addition of organic manures/ composts along with inorganic fertilizers results in improved soil aggregation and greater carbon sequestration especially in macro aggregates (Benbi and Senapati 2010; Sodhi et al. 2009). With the application of nitrogen and phosphatic fertilizer together the SOC increased at the rate of by nearly 250 kg ha^{-1} over 18 years in North China (Ludwig et al., 2010; Ludwig et al., 2012). In corporation of organic manures includes decomposition of organic matter where roots, hyphae and poly-saccharides bind clay particles into micro aggregates bind to form C rich macro aggregates. This type of C is physically protected within macro aggregates. The free primary particles are cemented together into micro aggregates by persistent binding agents characterized by humification of organic matter and stimulated accumulation of C aggregates.

Nutrient management is one of the most practiced techniques for food production. However, the imbalanced and excess use of chemical fertilizers has affected the land and environment adversely. The balanced and integrated uses of nutrients have proven benefits, and the policy of fine-tuning including innovative marketing strategies must follow for its large-scale adoption.Biofertilizers and urea may be bundled while selling the chemical fertilizers. Purchase of biofertilizer may be made compulsory for every bag of urea to promote use of organic nutrients and reduce the use of chemical fertilizers. Drip fertilization technique need to be promoted in which fertilizer is combined with irrigation water in the drip systemwhich conserves >40% nutrient and cut down water use by 50% (The Economic Times, 2020). Task force constituted by Govt. of India also suggested formation of crop based nutrient requirements to curb excess use of chemicals and fertilizers. Advisories should be issued; urea should be brought under nutrient-based subsidy (NBS) policy for better subsidy management. The Task Force also recommended in creating infrastructure in the villages for soil testing lab, agri clinics and agri-business centres for promotion of soil test based application of fertilizers. We must establish leaf analysis advisory laboratory for setting standard of fruits and other perennial crops. A clear picture of what the crop is experiencing

Table 1: Imbalanced nutrient (NPK) usage

Sates	Nutrient (NPK) usage (kg/ha)	NPK ratio (Ideal ratio: 4:2:1)	Proposed strategy for promoting balanced use
Punjab	210.1	19.9: 5.9: 1	• Promoting mixed fertilizers with various combinations and customizing subsidy as per formulation. • Promoting/incentivising integrated source of nutrients –bundling of bio fertilizers with chemical fertilizers. • Soil test based application of nutrients. • Encourage corporate farming with high degree of resource sensitivity. • Awareness of benefits of balanced fertilization, and the adversity of imbalanced use.
Haryana	166.7	29.6: 8.8: 1	
UP	140.4	12.1: 4.1: 1	
Ap	203.6	4.5: 2: 1	
Orissa	57.3	4: 1.5: 1	
Maharashtra	84.5	3.2: 1.8: 1	
West Bengal	127.5	23: 1.3: 1	

from weather and disease can be seen from a leaf analysis (The Economic Times, 2020). The present use of fertilizer is far from balance (Table 1), which causes not only poor efficiency but also soil and environmental degradation (Sanyal and Chatterjee, 2007).

Policy fine-tuning, technological advancement for fertilizer preparation, and application, promoting formulations including coated and mixed fertilizers, site specific soil test based nutrient management are the viable option for improving the farm income.

In order to ensure correction of hidden deficiencies of micronutrients, Govt. of India has approved zincated urea and boronated super phosphate under Fertilizer Control Order (FCO) besides use of straight fertilizers of zinc sulphate, iron sulphate, manganese sulphate, copper sulphate, borax, and sodium molybdenum. *Fertilizer microdosing*is another technique developed by the International Crop Research Institute for Semi-Arid Tropics (ICRISAT). It is a practice of application of micronutrients to the crop with appropriate quantity and at right time. This method helps thousands of farmers in western and southern Africa to get their crops to mature faster and overcome the drought effects.

Soil amendment in INM, like biochar having high porosity also contributes towards increased water retention and helps in climate change adaptation. Further, the particulate nature of biochar combined with a specific chemical structure enables it to give resistance to microbial degradation in soils (Cheng et al., 2008) Moreover, when applied to sandy soils, it may also contribute to reduce the nitrous oxide emissions from these soils. On the adaptation font, it could increase the water holding capacity of soil by 11% (Cayuela et al, 2014). Therefore, the site-specific INM practices could be considered as a component of 'Climate Smart Agriculture' as it would increase the farmers' adaptation to climate change impacts (e.g., by increasing the buffering capacity of soils to water and nutrients), reducing GHG emissions (by increasing yield; soil carbon sequestration; increasing nutrient use same time enhancing the food security (by sustaining crop yields and farmers income)A comprehensive literature search revealed that INM enhances crop yields by 8-150% compared with conventional practices, increases water use efficiency and the economic returns to farmers, while improving grain quality and soil health and sustainability . Evidences indicate that INM practice could be an innovative and environment-friendly strategy for sustainable agriculture worldwide. In addition to facilitating adaptation to climate change in the agriculture sector, the INM approach is also sensitive to changes in climatic conditions and could produce negative effects if soil and crop nutrients are not monitored systematically and changes to fertilizer practices are not made accordingly. In the case of small scale farmers, these costs may represent too high a proportion of the total variable cost production, thus ruling out an inorganic fertilizer as a feasible option.

Soil Organic Carbon Management

Organic fertilizer applications can improve soil functionality and significantly increase SOC levels. Thus, applying organic amendments, including biosolids and composts, to agricultural land can increase carbon storage and contribute significantly to offsetting GHG emissions. Studies have shown that manure can potentially increase crop yields and soil organic contents in comparison with mineral fertilizers (Jing et al., 2019). A 37-year field study showed that organic fertilization increased soil carbon input by 25% to 80%, although levels of carbon retention ranged from only 1.6% for green manure to 13.7% for fresh cattle manure (Maltas et al., 2018). Similarly, Bolan et al. (2013) demonstrated that biosolid applications likely result in higher levels of carbon sequestration compared to other management strategies including fertilizer

application and conservation tillage. This was attributed to an increased microbial biomass, and Fe and Al oxide-induced immobilization of carbon (Bolan et al., 2013). Although the amount of SOC in Indian soils is relatively low, ranging from 0.1 to 1% and typically less than 0.5%, its influence on soil fertility and physical condition is of great significance. Indian soils classified under Inceptisols and Entisols contribute about 22 and 7% of the total SOC stock, respectively. Vertisols are extensive in the central and southern part of India and contribute about 13% of the total SOC stock. Whereas arid soils belonging to arid ecosystem contribute 37% of the total SOC stock mainly because of large area occupied by them. Most of Alfisols occur in sub-humid to humid regions of the country and contribute about 20% of the total SOC stocks. The low SOC concentration in Indian soil is attributed to extractive practices of nutrient mining because of low or imbalanced fertilizer use, removal of crop residue for fodder or household fuel and soil degradation. Increasing carbon content in the soil, through better management practices, produce a number of benefits in terms of soil biodiversity, soil fertility and soil water storage capacity and hence productivity. Soil carbon sequestration through the restoration of soil organic matter can further reverse land degradation and restore soil health through restoring soil biota and the associated ecological processes.

The organic matter in soils under integrated nutrient management was found to be a key attribute of soil quality which has shown far-reaching effects on physical, chemical and biological properties of soil indicating necessity of addition of crop residues and organic manures in conjunction with chemical fertilizers for securing soil quality under intensified agriculture. In India, several long-term experiments carried out between 1971 and 2000 on different cropping systems under different agro-climatic zones indicate that application of balanced fertilizer NPK with FYM resulted in the build-up of SOM more than the fertilizer alone treatment (AICRP-LTFE,2013)

Sustenance of soil productivity with continued timely applications of balanced fertilizers along with FYM in Inceptisol, Alfisol and Vertisol has clearly been indicated. Researchers have also observed that the long-term effect of continuous integrated nutrient management and adoption of easily available options of practicing green manuring, addition of crop residues and organic manures in conjunction with chemical fertilizers in balanced form are efficient for building up of the active carbon fractions in soil which is important for enhancing soil quality. Based on 12 rice-based long- term experiments from different locations of India, Pathak et al (2011) reported that NPK + FYM treatment has good potential for C sequestration and improvement of soil health (Mandal et al., 2007, Masto et al., 2006). Apart from conventional organic sources for soil C sequestration, a pyrogenic carbon or black carbon (BC) referred to as biochar application of which as soil amendment may act as an important long-term carbon (C) sink because its microbial decomposition and chemical transformation is probably very slow. Biochar can be used to hypothetically sequester carbon on centurial or even millennial time scales. There are also many examples from India of improvements in SOM content with adoption of conservation agriculture (CA) and complex farming systems (Chaudhari and Biswas, 2017).

Knowledge transfer

A myriad of scientific knowledge exists regarding best practice forsoil management. However, there has been a general lack of adoptionby farmers . This can be attributed to obstacles that hinderthe distribution of relevant scientific information. Scientific evidencefrom in-depth studies is often scattered within variousdisciplines that use technical jargon that is little understood by the socialscientists or journalists who are engaged in information transmittaland knowledge sharing. Modern electronic information sharing techniques, including social media tools (e.g., Twitter and Facebook) makemass information distribution easier, but they canalso make it difficult for lay people to distinguish between evidence basedreliable information and inaccurate or even misleading information.

Information management and knowledge sharing may help to fillthe gap between knowledge generation and its useful application. Thisis particularly important for the application of soil science. A variety ofsoil information management and knowledge sharing mechanismsexist, including training workshops (online or offline), websites, socialmedia, advisory services.

Carbon Sequestration through Land Reclamation and Management

The capacity of land sink for capturing C progressively declined from 28.1% to 24.2% over a period between 1970 and 2006 (Canadell et al., 2007). Some improved soil management practices for capturing and storing carbon with favourable impact on soil structure include growing cover crops, sowing crops with conservation tillage, maintaining balance level of soil fertility, and converting marginal and degraded lands to restorative land uses (Fig. 1).

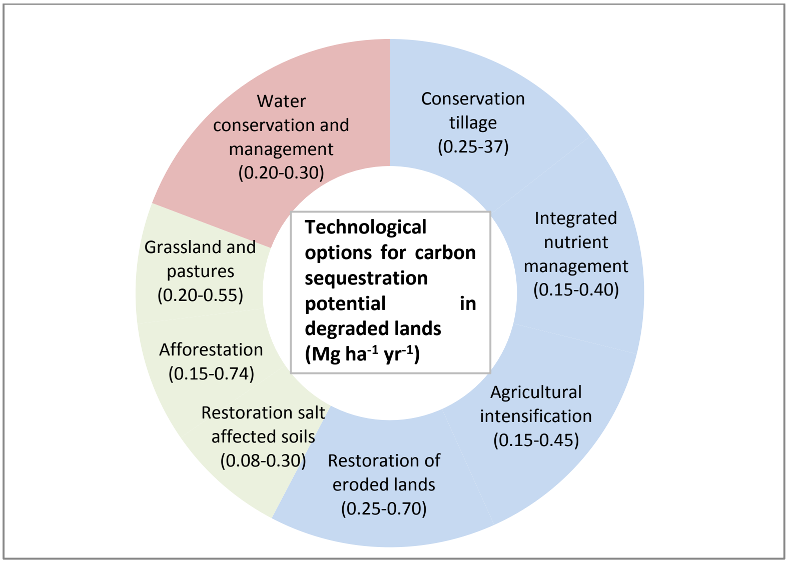

Fig. 1. Carbon sequestration potentials (Mg ha^{-1} yr^{-1}) of various land management options in tropical soils

Improving soil's resistance to forces causing detachment and transport involves enhancing soil structure. Any land reclamation practice which improve soil structure and enhance soil quality lead to C sequestration. Once the C is captured and retained in the soil, the life of enhanced SOC can be maintained only through restorative land use practice and recommended management practices (RMPs). Soil's capacity for C sequestration depends on mineralogy, clay content, temperature, moisture regimes and aggregate forming ability (Lal, 2004).

Conclusion

Worldwide, overgrazing, deforestation and other exploitative land systems caused land degradation and attendant SOC depletion in many land based ecosystems. Historically, soils have lost 40-90 Pg carbon (C) globally through cultivation and disturbance at a rate of about 1.6 0.8 Pg C y-1, mainly in the tropics. Since soils contain more than twice the C found in the atmosphere, loss of C from soils can have a significant effect on atmospheric CO_2 concentration, and thereby on climate. Halting land-use conversion would be an effective mechanism to reduce soil C losses, but with a growing population and changing dietary preferences in the developing world, more land is likely to be required for agriculture. Maximizing the productivity of existing agricultural land and applying best management practices to that land would slow the loss of soil C. There are, however, many barriers to implementing best management practices, the most significant of which in developing countries are driven by poverty. Management practices that also improve food security and profitability are most likely to be adopted. Soil C management needs to be considered within a broader framework of sustainable development. Policies to encourage fair trade, reduced subsidies for agriculture in developed countries and less interest on loans and foreign debt would encourage sustainable development, which in turn would encourage the adoption of successful soil C management in developing countries. Likewise, a widespread adoption of RMPs by resource poor farmers of the tropics is urgently warranted. If soil management is to be used to help addressing the problem of global warming, priority needs to be given to implementing such policies.Specifically the following conclusions can be dwawn.

Current evidence is clear that a site-specific nutrient management using a combination of mineral and organic fertilizers, combined with other good agronomic practices, can deliver optimal results for farmers and for food security. However, the authors highlight the need for additional research to provide policy-makers and farmers with a regionally nuanced evidence base that will further encourage widespread adoption of SOC-enhancing practices.

1. Sensors to detect nutrient deficiencies and early warnings of nutrient deficiency for precisely targeted control.
2. Use of aerial and global positioning technology for precise application of fertilizers- How much where and when it is needed in a field or forest.
3. Just in time, irrigation, fertilization that maximize water and nutrient use efficiency.
4. New technology with novel formulation of fertilizer materials and soil amendments based on nanotechnology and plant growth regulators (PGRs).
5. Smart fertilizers might be developed to release nutrients upon demand by the plant in response to specific molecular signals (Meeting et al., 2001).

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Controlling Groundwater Depletion: Building Strategies through Water Management and Artificial Aquifer Recharge in Agricultural Land

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Introduction

About 60% of irrigated agriculture in India depends on groundwater pumping (Shah et al., 2003). The number of tube wells has increased from < 1 million in 1960 to ~ 24 million in 2014 (Saha and Roy, 2018). As a result, groundwater extraction in India has accelerated from 25 BCM in 1960 to 250BCM by 2015 (GoI, 2019). Thus, India is now the largest groundwater extractor in the world (Shah, 2014). Overexploitation of groundwater has become a severe environmental problem (Reddy 2005; Palanisami *et al.*, 2008). In many parts of India, the rate of groundwater extraction has surpassed the rate of replenishment resulting in the decline of the groundwater table (Deb Roy and Shah 2003). About 17% of blocks are categorized as overexploited i.e. groundwater withdrawal exceeds the recharge rate of aquifer, and 5% and 14% respectively, are critical and semi-critical stages (CGWB, 2019). The economic survey 2021-22 states that groundwater extraction has been increased by 4% in last decade as compared to 58% of year 2004 (Fig. 1). The situation is the worst in north-western, western and southern peninsular regions, and depletion is at alarming rate. The rice-wheat growing north-western states including Haryana and Punjab are facing groundwater depletion the most (Kamra et al., 2010). The groundwater extraction in these states is >100%, which is a great cause of concern for sustainable agriculture. About 76 and 61 percent blocks in Punjab and Haryana, respectively are overexploited while the national average is 60% (Times of India, 2023 https://timesofindia.indiatimes.com/city/chandigarh/groundwater-extraction-worst-in-punjab-haryana-close-3rd/articleshow/97833233.cms?from=mdr, 12 Feb, 2023). Thesubstantial spatio-temporal variation in heavy stressed groundwater and its forcing mechanisms is observed (Joshi et al. 2021). In north-west India, the groundwater depletion rate is estimated as 0.33 m/year (Rodell et al. 2009). However, in last decade, groundwater decline rate in Haryana increased to 0.88 m/ year (Narjary et al. 2014). If this trend continues, it will not only affect the socio-economic conditions of the farmers, but eventually cause irreversible

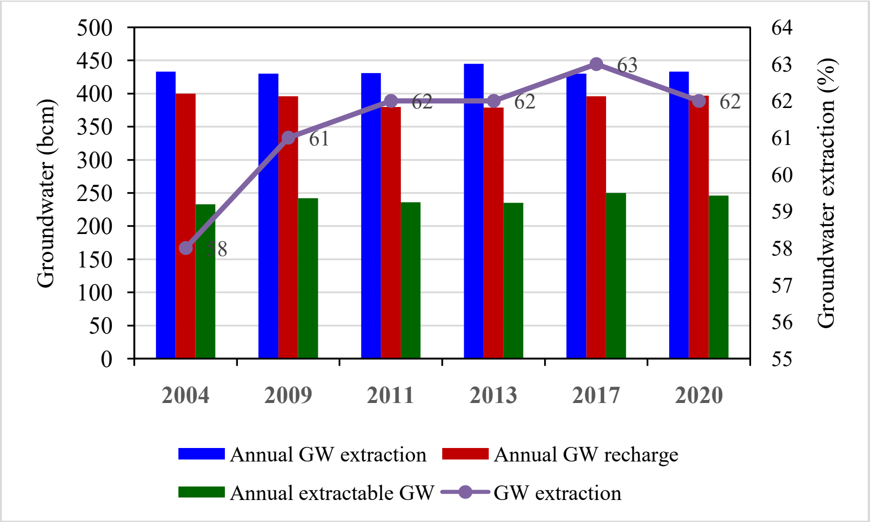


Fig. 1: Categorization of Ground Water Resource Assessment Units (2004-2020)

(Source: National Compilation on Dynamic Ground Water Resources of India, 2020)

damage to the aquifers and regional ecological balance. Also, the evident precipitation patterns (higher variability of rainfall with more number of high intensity short duration storms) coupled with rapid urbanization/ shrinkage of agricultural land during the last few decades resulted in decreased natural groundwater recharge. Hence, sustainable groundwater management demands initiatives of reduced groundwater pumping for irrigation, enhanced runoff utilization and induced aquifer recharge. The lowering groundwater demand through on-farm rainwater harvesting and effective use of unutilized runoff for aquifer recharge can be a powerful response to the threat posed by groundwater depletion to the sustainability of agriculture.

Management strategies to control groundwater depletion

Building management strategies to control groundwater depletion is a daunting task considering varied crops, geology, climate, hydrology, socio-economic conditions and groundwater utilization pattern, and, definitely, the 'one-size-fits-all' approach is not going to work (Jha and Sinha, 2009). In general, strategies to control groundwater depletion can be categorized into two broad categories i.e. augmenting groundwater resources are reducing its withdrawal. Enhancing aquifer recharge artificially usingrain and excess canal water supply could defer groundwater depletion to some extent. While minimizing the gap between demand and supply of agricultural water by adopting on-farm water saving practices could also help to a great extent. The effective utilization of rainwater in agricultural field will definitely reduce the dependency on groundwater and subsequently its withdrawal.

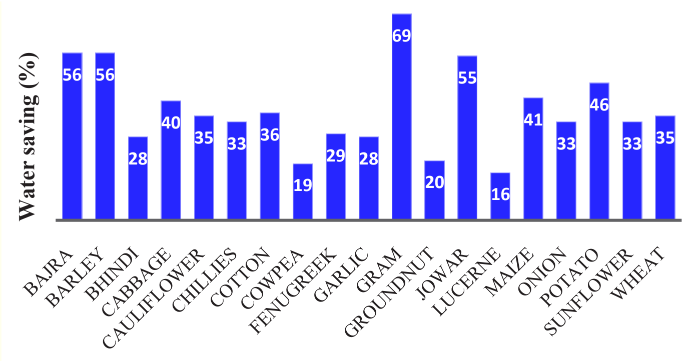
The measures such as efficient irrigation systems, growing less water requiring crop, agronomic practices to enhance on farm rain water harvesting, runoff water storage and groundwater augmentation using farm ponds and check-dam and artificial groundwater recharge in agricultural land could be effective interventions to control depleting groundwater resources.

Measures to reduce groundwater withdrawal

Adoption ofefficient irrigation system

The sprinkler and microirrigation (drip) are considered to be the most efficient way of water application to the crop. The average water application efficiency is about 75% and 90%, respectivelyfor sprinkler and drip irrigation system, as compared to merely 40% of the conventional method of irrigation. Though, drip system has better application efficiency, but sprinkler irrigation can be more cost-effective. The two-thirds reduction in excessive groundwater extraction could be achieved by adopting efficient irrigation methods which may help in sustaining groundwater (Fishman *et al.* 2015). The field investigation carried out in different parts of India indicated the substantial saving of irrigation water by sprinkler and drip irrigation over surface method (Fig. 2). Hence, shifting to micro irrigation system reduces water application by 30%–60% (Postel et al. 2001) and subsequently pumping of

(a)



(b)

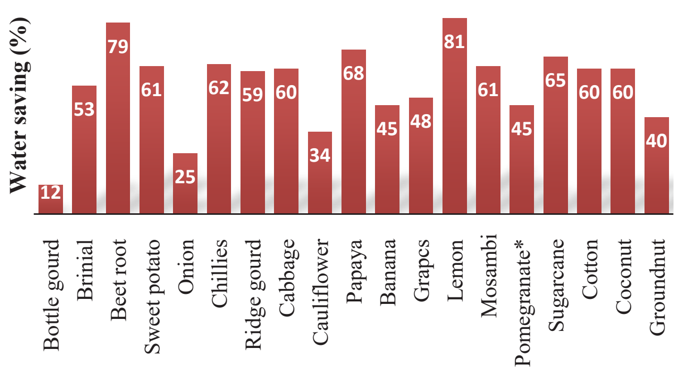


Fig. 2. Irrigation water saving (%) as compared to conventional method by adoption of a) drip and b) sprinkler irrigation system

groundwater for irrigation per ha by 30 to 70% (Shah 2009) based on season and crop. In a study in south India, it was found thatmicro-irrigation helps in saving water and labour in the range of 30 to 69% and 21 to 42 man-days per ha, respectively (DES Karnataka, 2013). In view of water saving potential of sprinkler and drip irrigation systems and considering the increasing pressure on groundwater resources, government of India is aggressively promoting these efficient irrigation techniques through different sponsored schemes to achieve the sustainable management of depleting groundwater (Birkenholtz 2017, Sikka et al 2022).

Though state and central governments are promoting adoption of these system since the 1980s with providing financial assistance, however climate change threats necessitated to enhance its adoption pace and governments have also started various schemes to achieve the goal (Birkenholtz 2017). The first Centrally Sponsored Scheme 'Per Drop More Crop' through adoption of micro Irrigation system was launched in 2006, but, now it is an important constituent of the scheme 'Pradhan MantriKrishiSinchayeeYojana' launched in 2015 to enhance water application efficiency in cropped land (https://pmksy.gov.in/ microirrigation/ index.aspx). With these efforts, area under drip at present is about 47 lakh hectares, however it is only about 17.4 per cent of the total potential area (Jain et al 2019, Gupta et al 2022). Further, adoption of drip irrigation in Indo-Gangatic plane is merely 0.1%–2.5% of the total potential (Palanisami et al 2018).

It is proven that in dry year (deficit rainfall), shifting to drip system from flood irrigation method could help to mitigate depleting groundwater (Sishodia et al ,2018). It is also evident that use of drip system in rice –wheat and maize wheat crop rotation can save 40-47% of irrigation amount which may translated into lower groundwater extraction (Sharda et al. 2017; Jatet al., 2019). But, groundwater recharge from the agriculture field may be altered and thus, there is a need of a systematic study to know the net impact of adoption of these systems on groundwater resources.

Shifting to less water-intensive crops

The groundwater abstraction can be regulated by adopting suitable cropping patterns, particularly in critical and over-exploited regions (Singh and Singh, 2002). Unstainable crop choices and practices have led to excessive drilling of bore-wells and groundwater exploitation (Babu and Manasi, 2008). For example, in the northwestern states of the country where climate is mostly semiarid, despite of that rice-wheat is the major crops that requires approximately 2100 mm of groundwater withdrawal for crop production (Jalota et al. 2018). Therefore, growing less water-intensive crops like maize, mustered, millets etc. instead of water guzzling crops such as rice, wheat and sugarcane could be an effective measure to mitigate the groundwater decline (Minhas et al., 2010). Hence, maize-wheat cropping pattern over the prevailing rice-wheat in IGP can be better option for controlling groundwater declining (Jalota and Arora, 2002). The irrigation requirement of millet and pulses is considerably less as compared to rice, wheat and sugarcane crops ((Fig. 3) Replacing wheat during *Rabi* (winter) season with less water requiring crop like mustered can help in controlling groundwater depletion further. In IGP, water deficit (ET-rainfall which governs groundwater decline), consider as driving force behind groundwater abstraction is more during the wheat growing

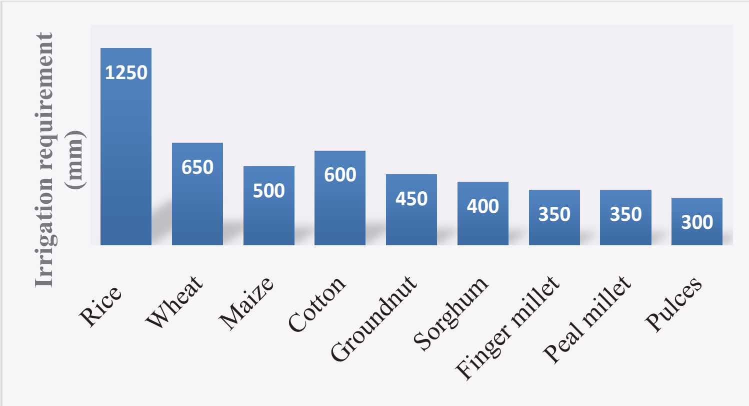


Fig. 3: Irrigation requirement of various crops

period and thus crop diversification in winter season will help in reducing groundwater pumping (Jalota et al. 2018; Bhattarai et al., 2021).

Replacing 20%, 30%, and 40% rice area by maize in rice–wheat system can reduce mean (average of RCPs) groundwater decline by 7.1 (24.9%), 10.1 (35.3%), and 13.8 (48.5%) m, respectively, in comparison to the projected end century (2099) decline of 28.50 m under prevailing rice–wheat cropping system. Further, replacement of 80% rice area by maize crop could reverse declining groundwater trend of rice–wheat in the study region of IGP. Such replacement would help to raise groundwater table depth by 2.4, 6.20, and 9.0 m under RCP4.5, RCP6.0, and RCP8.5, respectively, by the end century (2099) over that of reference groundwater level of 18.5 m in the prevailing rice–wheat system (Fig. 4).

However, replacing the water-intensive cropping pattern should not be contradictory with farm incomes, an incentive mechanism needs to be put in place. For instance, in Haryana, state government has implemented an incentivizing scheme for promoting maize, pulses, and oilseeds crops instead of paddy. Similarly, the state can also provide incentives for the cultivation of coarse millets and oilseeds, which will reduce the abstraction rate of groundwater and promote the production of these crops, which are also increasingly preferred by health-conscious consumers.

Shifting sowing/transplanting date

The transplanting date of rice has significant effect on irrigation requirement and groundwater withdrawal. In IGP, transplanting of rice is recommended in the mid to late June. However, to enhance rice area, farmers some time advance the transplanting date in May which coincides with the peak summer and evapotranspiration demand is on the peak (12mm/day). The advancement in date of rice transplanting to May demands about 180–240 cm more irrigation (Barar et al. 2012). It is therefore advised that to select a suitable date of transplanting which have minimum total crop ET during the crop growing season. For example, in semiarid climate of Ludhiana, historical data indicates that ET vary between 53

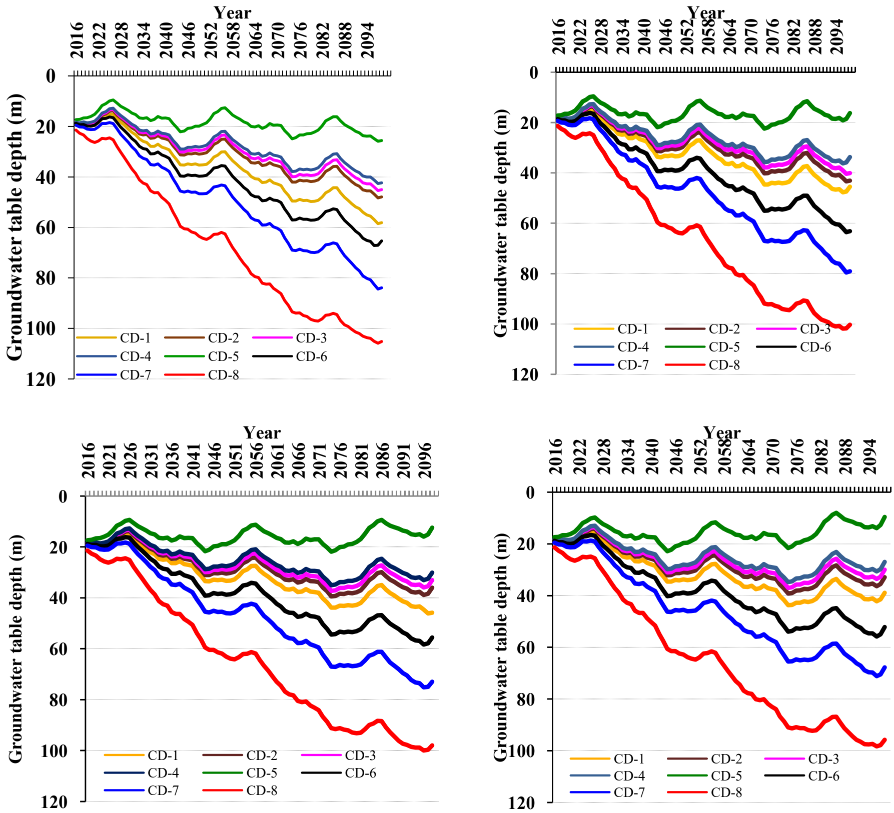


Fig. 4: Simulated groundwater table depth (distance in m below ground level) under different crop diversification scenarios (CDs) for (a) RCP 2.6 (b) RCP 4.5 (c) RCP 6.0 and (d) RCP 8.Where CD-1: entire cropped area under rice during Kharif using existing water supply; ii) CD-2: 20 and 80% cropped area under maize and rice, respectively during Kharif, CD-3: 30 and 70%cropped area under maize and rice, respectively during Kharif, followed by wheat using existing water supply, CD-4: 40 and 60% cropped area under maize and rice, respectively during Kharif, CD-5: 80 and 20 % cropped area under maize and rice, respectively during Kharif; CD-6: entire cropped area under maize during Kharif, CD-7: entire cropped area under maize-wheat cropping using GW supply only and CD-8: entire cropped area under rice-wheat using GW supply only.

to 77 cm for the different transplanting dates spanning from May to July (Fig.5). Therefore, if transplanting date is chosen in such a way that crop realize the minimum ET without compromising the yield, would be a great help to controlling groundwater depletion. Similarly, in rice-wheat cropping system in IGP, reported that prevailing dates of transplanting/sowing are 15 June and, In rice wheat crop rotation of IGP, 10 days advancing of wheat sowing date from the prevailing 15 November has shown potential to reduce groundwater decline (Kumar et al. 2022).

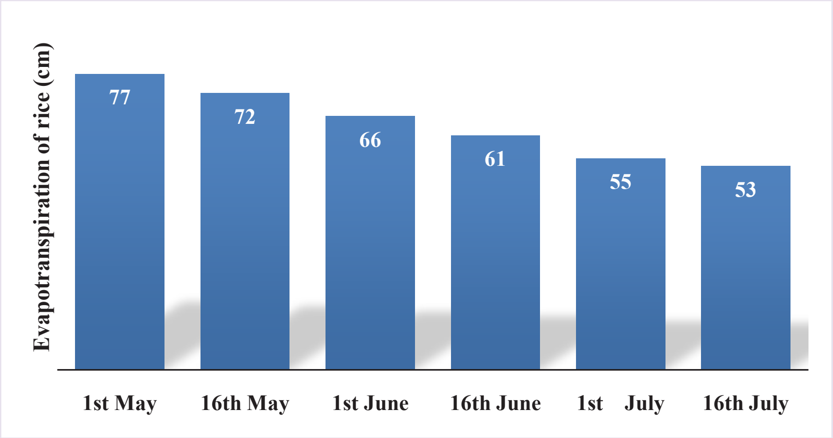


Fig. 5: Evapotranspiration of rice with different transplanting date in semi-arid region (Ludhiana)

Rain water harvesting in paddy field

Rainwater harvesting in paddy fields implies the aim that "khetkapanikhet men", means store and utilize rainwater within the field. To store and utilize rain in the paddy field involved two process i) check water flow (runoff) from the field by increasing bund height and ii) adopt proper irrigation schedule that provide opportunity of maximum utilization of rain water for crop production. In semiarid region of Ludhiana (Pumjab), the effective allowable storage depth (bund height) of 12.5 cm can minimize the system loss (groundwater withdrawal-recharge) to merely 1.18 cm (Table 1) under improved irrigation practices i.e. subsequent irrigation was scheduled after 2 days of disappearance of water from the field surface (Khepar et al. 1099). Thus, groundwater deficit during rainy season can be easily managed through rainwater harvesting in paddy field in IGP.

Table 1: Irrigation water requirement, runoff and system loss as influenced by irrigation Practice

Allowable Rainfall storage depth(cm)	Traditional irrigation practice			Improved irrigation practice		
	Irrigation applied (cm)	Runoff (cm)	System loss (cm)	Irrigation applied (cm)	Runoff (cm)	System loss (cm)
7.5	100.94	21.11	14.44	88.48	15.55	8.88
10	93.01	13.59	6.92	84.49	10.94	4.27
12.5	89.91	9.25	3.12	81.65	7.85	1.18
15	86.69	7.29	0.63	79.96	6.47	-02
17.5	85.89	5.78	-0.80	78.54	5.0	-1.67
20	84.80	4.85	-1.82			

Rainwater harvesting and utilization through farm pond and check dam

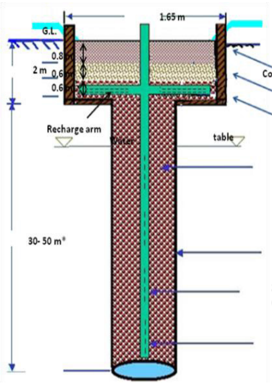
In India, rainwater harvesting and utilization in farm pond,tanks, talab or in pokhar is practiced from the ancient time.These are less capital-intensive water storage facility but provide multiple ecosystem services (Palanisami and Easter, 2000; Babu and Manasi, 2008). Unfortunately, the area under talab/farm pond has been continuously declining due to human encroachment (Narayanamoorthy, 2007). Though, it has multiple benefits such as store rainwater when it in excess, save crop and building from erosion and more importantly stored water is available for crop production during the lean period. The farm pond also acts as percolation tank recharges groundwater aquifer. Similarly, check dam, a temporary or permanent structure placed across the stream flow,creates water pool at upstream side and enhances groundwater recharge. The stored water is also used for supplementary irrigation during off season. Therefore, farm ponds and check dam are cost-effective structures of rainwater harvesting and recycling that can transform rural economy through sustainable agriculture. The may help in increasing crop intensity and farm income. Thus, these structure can be used successfully for storage of unutilized runoff water for crop production as well as augmenting groundwater.

Artificial Groundwater recharge from agricultural lands

With the rapid infrastructure development, particularly rail and roads, land lock area i.e. natural drainage is hampered, is now a very common feature. Almost in every village, low lying field are where runoff gets accumulated while extreme rain takes place and affects adversely to the crop, and some time damage to infrastructure also. There is need of hour to dispose that water rapidly to save crop and infrastructure. However, it requires location specific drainage option. Artificial groundwater recharge structure can serve the purpose, with the disposal of water in to aquifer at the faster rate than natural recharge.

A number of agencies in India including the Central Ground Water Board (CGWB), research institutes, universities and non-governmental organizations (NGOs) have undertaken various studies on artificial groundwater recharge (Chadha,2002). However, a limitation with these big artificial groundwater recharge structures was found as poor post-installation maintenance due to common liability. In view of post installation limitation of big structure, ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal, designed and developed small recharge structures which can be suited to individual farmer (Kamra et al. 2010). To safeguard against clogging, runoff water was first passed through a filtering unit consisting of layers of coarse sand, gravel and boulders and perforated pipe wrapped with synthetic filter in a small brick-masonry chamber (Kumar *et al.*, 2012; Kumar *et al.* 2014). The design details of developed and demonstrated structures are described below

i. Recharge Shaft : The recharge shaft consists of a bore hole of 45 cm φand varying depths filled with gravel pack of 1.5 – 2.0 cm φto carry filtered recharge water to subsurface sandy zones. To safeguard against clogging, the surface runoff from rainfall or excess canal water is first passed through a graded recharge filter consisting of layers of coarse sand, small gravel and boulders in a small brick masonry chamber. A high pressure PVC pipe, of 12.5 cm φ and slotted in sandy zones, is provided in the middle of the shaft to circulate compressed air for cleaning of clogged sediments in the shaft after a couple of years. The depth of recharge shaft is decided based on the criterion to provide 10- 15 m cumulative sand layers for recharge.

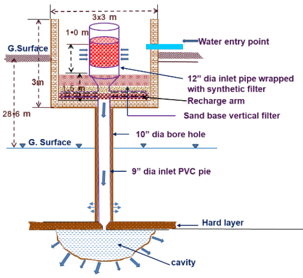


ii) Recharge cavity:

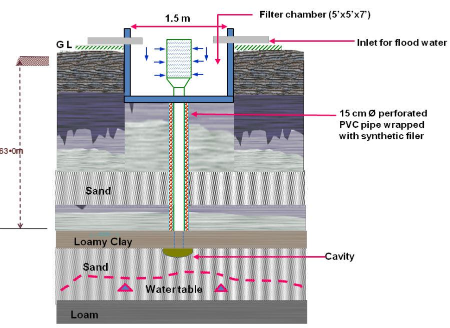
The recharge cavity consists of a conventional cavity tube well coupled with a recharge filter similar to the one described above in recharge shaft for recharging of excess water and can also be used for occasional pumping.

iii) Abandoned cavity:

Abandoned tube well can also be converted into drainage cum recharge structure by providing suitable option for retaining physical impurities carrying with the runoff water. Filtration option consists of brick masonry and larger size perforated pipe wrapped with nylon net which is fixed with abandoned tube well pipe. The perforation is in upper 3 ft and 1.5 ft pipe length at the bottom is kept blind to facilitate sedimentation.



Recharge cavity type structure



Abandoned cavity type structure

Performance appraisal of developed recharge structures

The encouraging results on the effectiveness of recharge shaft and recharge cavities to replenish groundwater and improve its quality was found. Recharge rates of 6- 10 litre/sec were estimated for 4 recharge cavities (2 abandoned, 2 new) provided with differently designs and timely cleaned radial filters in Haryana. It is seen that recharge events, indicated by arrows, cause both a rise in water table depth beneath the structure and reduction in EC as well as RSC of groundwater. The improvement in salinity and RSC of groundwater at different selected sites in Haryana and Punjab ranged from 0.3- 2.4 dS/m and 0- 4.46, respectively.




Conclusion

Any efforts on reducing groundwater withdrawal or enhancing aquifer recharge will definitely help in controlling groundwater depletion. However, it is going to be very complicated owing to the climate change. Anticipated changes in temperature and rainfall in coming future will not only affect the irrigation demand and groundwater withdrawal, but also project increase in rainfall intensity may affect aquifer recharge. Under these circumstances, a comprehensive effort would be needed to tackle these challenges through economically viable technology and policy support. The approach discussed above could be a solution to the emerging issues but location specific selection and refinement of the intervention would be the key. The crop diversification with the maize in monsoon season in IGP may require drainage option at certain low lying area, where farmers based recharge structure can serve the purpose. But, practical designs of recharge filters and quality of water being recharged should be the focus of current research. Similarly, to reduce crop water demand in rice-wheat rotation, efforts should be promoting short duration varieties or less intensive crops with the financial incentive to the farmers for enhancing adoptability of water saving approaches.

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Next-Generation Climate-Resilient Management of Water and Watersheds: From Data to Action

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Introduction

In an era marked by the pressing challenges of climate change and growing water scarcity, the global conference lead paper titled "Next-Generation Climate-Resilient Management of Water and Watersheds: From Data to Action" will represent a pivotal involvement to the field of environmental management and sustainability. This innovative paper delves into the predominant core issues surrounding integrated management and development of watersheds and water resources as whole. It offers a comprehensive framework that leverages advanced data analytics and technology-driven solutions to tackle the multifaceted challenges posed by climate variability and watershed sustainability. The central theme of the paper revolves around the urgent need for adaptive and climate-resilient strategies to manage water resources and watersheds effectively. It underscores the profound impact of climate change on water availability, distribution, and quality, emphasizing that historical approaches to water resource management are no longer sufficient in the face of these evolving challenges. Author has attempted to share his 4 decades profound experiences on watershed planning, development, management, monitoring and policy-based ingredients; encompassing his enriched operational and applied exposures of working in more than 25 natural watersheds cutting across 6 states of India and dozens of applied catchment dealings under variety of climatic, physiographic and land use configurations.

Key Highlights/Ingredients of Lead Paper

- Central objective remains to explore and share present days critical intersection of climate resilience, data-driven decision-making, and sustainable water resource management. Apart from fundamental principles (basic, applied, operational, advanced, smart) involved in managing water and watersheds, a comprehensive portrait is offered with a demand driven blend of long-standing, refined, smart technology & concept driven, and futuristic matrix of managerial elements is made as central leitmotif of this lead paper.

The presentation remains innovative that will delve into the urgent need for climate-resilient solutions, the role of data in this endeavour, and the actionable strategies that will lead us toward a more secure water future, in agricultural sector.

- Beside sharing educations emerged from real ground executions in variety of R&D projects on water resources supervision and watershed management in particular; the presentation comprises an updated stuff of knowledge and wisdom towards issues like (1) Concept of climate resilience in water management and urgency of addressing climate change impacts, (2) Role of data in climate-resilient water management, (3) Next-generation tools &technologies towards water and watershed sectors, (4) Interconnectedness of water resources and ecosystems, (5) IoT, Remote Sensing, AI, and their applications in water management at varied scales with few real world application examples, 6) Emerging trends and challenges towards realistic observations, analytics , demand driven solutions, decentralized management keys, and dually mandated engagements at varied levels and scales, and finally the (7) Data driven decision making using cutting-edge data collection, analysis, and modelling techniques.
- Conceptual frameworks and prevailing benefits of real-time monitoring and data analytics for decision-making in watershed or water related systems/projects are also involved in the presentation with prospects of monitoring to offer instant access to critical water data, and thus enabling quick responses to emerging situations, such as extreme weather events or even the water quality fluctuations. In also encompasses prospects of developing early warning systems that can alert stakeholders to potential hazards, such as floods or droughts, and thus minimizing perilous damage and risks via optimized water resource allocation/conservation.
- Importance, capabilities/utilities of water data analytics is touched offering conceptual insights for identifying areas of need, reducing wastage, and the best possible accuracies. It may provide a record of actions taken and outcomes achieved, supporting accountability, transparency, and lessons learned for future decision-making in regards to conservation, management and development of water and in particular the rainwater at varied spatio-temporal scales. Operational importance of few smart versions of water analytics are advocated for their adaptability in current days integrated watershed management programs, ensuring water as their nuclei.
- Community engagement, stakeholder collaboration, resilience, adaptation, policy frameworks/recommendations, technologic innovations, best practices, and impact scrutiny are highlighted; in light of next-generation watersheds for promoting data-driven, integrated, and community-engaged approaches actionable insights to guide policymakers, researchers, and practitioners toward a more sustainable and resilient future for our planet's most vital resource (i.e. water).
- Some of the best thinkable smart tools and technologies for advancing next-generation water management are deliberated in the presentation, projecting few amalgamations that may enable efficient, sustainable, and data-driven approaches in water sector. It involved a primary dialog in regards to (1) IoT sensors/devices to monitor water quality,

quantity, and water infrastructure in real-time, (2) Satellite and aerial remote sensing technologies for valuable information on water resources like assessment of groundwater levels, soil moisture, land use changes and vegetation dynamics, (3) Artificial intelligence prospects to process large datasets offering logical predictions, optimized water allocation, and detecting anomalies/trends in water usage and availability, (4) GIS technologies to facilitate mapping and visualizing water resources, infrastructure, and watersheds with due spatial analysis, planning, and decision supports, and (5) Real-time continuous monitoring of water infrastructure and even watersheds to detect faults, optimize operations, and improve water-asset management, (6) Cloud computing and blockchain approaches/platforms to facilitate storage, processing, and sharing of large volumes of water-related data among stakeholders, and advanced smart gadgets like unmanned aerial vehicles, drones, mobile apps, for aerial inspections, monitoring reservoirs, and assessing the condition of water infrastructure in remote or inaccessible areas.

- Beside rainwater and stormwater management explanations, emerging prospects of smart irrigation systems with optimized water usage in agriculture via active monitoring of soil moisture/weather-conditions/crop-needs, are too briefly projected to ensure higher water use efficiencies & water productivities with reduced water wastage.

- Next-generation concepts, tools, technologies, and managerial options for watershed management and development are pondered with the aim to address the increasing challenges posed by climate change, population growth, and environmental degradation. These innovative approaches are focussed to improve the sustainability and resilience of watersheds while promoting efficient resource use and community engagement. It will include a short reflection towards some key elements; like (1) Climate-resilient planningto anticipate/accommodate shifts in precipitation patterns, temperature, and extreme weather events, (2) data-driven decision-making by utilizing advanced data& its analyticsto monitor watershed conditions, assess risks, and informed management decisions, (3) Ecosystem-based approach that considers the interconnectedness of land use, water quality, biodiversity, and socio-economic factors, (4) Green infrastructure solutions to improve water quality and reduce erosion, (5) Added community based approaches via ownership of watershed management initiatives, (6) Specified infrastructure and strategies to mitigate the impacts of both floods & droughts, and (7) Blending multi stakeholder and market based approaches in watersheds programs.

- An updated panorama of watershed-based models and approaches for managing and conserving water resources within any pre-defined geographic area, is offered listing various watershed-based models and approaches, that prevails right now. The ultimate goals or action targets set herein are citation towards key models (HEC-HMS, SWAT, MIKE SHE, PRMS, MODFLOW, CE-QUAL-W2, QUAL2K, HSPF, STELLA, RUSLE, WEPP) and watershed management approaches (Integrated, Eco-system based, Community based, GIS based) that can offer valuable tools for understanding, managing/protecting watersheds and their resources in a sustainable/resilient manner.

- Rainwater management remains the fundamental issue for sustainable water resource utilization, which is pronounced in holistic way, blending it with updated options in terms of sensors, IoT devices, alternating data generating sources/techniques and big-data analytics. Access to open data sources and agencies for rainfall, water and watershed-based data and information is projected as one of the most important need of hour for researchers, hydrologists, watershed managers, field functionaries, policy planners. Some potential popular sources and agencies for water and watershed-based data are reflected in the presentation.
- At last a summarised conclusion is offered showing climate-resilient water management as a win-win approach that not only prepares communities and ecosystems for the impacts of climate change but also facilitate optimized water resource use building resilience to climate-related challenges. Importance of reliable ample data is debated taking it as a backbone of next generation wisdom in regards to water resource systems as well as natural watersheds of varied physiographic or ecologic configurations. In general, this lead paper offers a visionary roadmap for addressing the critical nexus of water management and climate change adaptation, by deliberating data-driven, integrated, and community-engaged approaches and thus the futuristic actionable insights to guide policymakers, researchers shaping the discourse on management of water and watersheds in years to come.

Agro-climatic Characterization for Risk Reduction in Agriculture

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Introduction

Climate plays a fundamental role in agriculture. Food production depends upon four factors namely plant and genetic material, weather, soil and water. Many other factors like management practices, size of the holding and enterprising nature of the farmer may also contribute to the success or failure of agricultural production. But weather plays a more decisive role and the farmer will have very little control over the weather. Weather will influence agricultural production through its effects on soil chemistry and physics, plant growth and development, yield and yield components and in every phase of animal growth and production and through various atmospheric stresses. So, the basic philosophy of agricultural meteorology is to make use of the science of meteorology in the interest of food production. The timeliness and effectiveness of agricultural operations depend on the weather. Any extreme change in normal weather conditions may cause damage to crops and soils. The quality of crop produce during movement from field to storage and storage to market depends on the weather. Therefore, to make the agricultural production system climate-smart, the use of weather/climate-related information and interventions thereof is the need of the hour.

Across the globe, investigation and dissemination of agricultural technologies are pursued as an intervention to raise agricultural production and improve the livelihoods of farmers. Reports around the world indicate that the ill effect of climate change on crop/livestock production is overweighing the positive effect. In order to insulate their livelihood, farmers can adapt to weather/climatic variability to a certain extent by manipulating the physical environment based on agrometeorological interventions. The concept of climate-smart agriculture (CSA) offers a set of approaches for altering and reorienting agricultural systems in a sustainable manner by focusing on the potential synergies and trade-offs between agricultural productivity and food security, adaptive capacity and mitigation benefits. Therefore, characterization of agro-climates and prioritization of farm level decisions can help in imparting resilience to the agricultural production system and make it climate-smart and risk free.

Agro-climatic characterization for risk reduction

The agricultural production potential primarily depends upon the availability of soil moisture and congenial thermal regime during the crop growing period. The agricultural climates all over the world are classified based on the two parameters i.e., the moisture regime and thermal regime. Besides that, light and occurrences of extreme weather events are also useful for efficient crop planning at the agro-climatic zone level, agro-climatic characterization is required. This characterization can be done using various agro-climatic indices. These agro-climatic indices can be very helpful for farmers in their decisions about crop management options and related farm technologies.

Delineating risk prone regions to Extreme Weather Events

In the recent years, due to climatic changes and warming of the earth's atmosphere, extreme weather events viz., cyclone, heat waves, cold waves, hailstorm, prolonged dry spells, flood etc. are on rise and also becoming more intensive. Therefore, identifying the regions prone to various extreme weather events and also estimating the chances of their occurrences will help in improving the preparedness to counter its negative impacts on crops and other enterprises.

Dry-spell characterization

The dry spells and deficit rainfall within crop season, play a vital role in determining the productivity of rainfed crops. A new index named Dry Spell Index (DSI) quantifies the cumulative impact of dry spells during *kharif* season (Jun-Sep) on major rainfed crops of India. District-wise variability of DSI was analysed across rainfed regions of India using rainfall data of 1636 stations. Comparison of DSI with Standardized Precipitation Index (SPI), hitherto, a widely used drought index showed that, central and eastern Karnataka, northern Rajasthan and western Gujarat are becoming wetter in terms of total seasonal rainfall as indicated by SPI, and becoming drier in terms of total dry spell duration within the season as per DSI.

Delineating crop-specific agro-ecological suitability

To sustain the productivity *vis-à-vis* food security and ecosystem health, adoption of location-specific diversified land-use practices including crop/ horticulture/ agroforestry considering the suitability of various agro-physical input parameters. In this regard, allocation/ adoption of specific land-use practices should be based on agro-ecological conditions to avoid over-exploitation of natural resources. Hence, in the changing climatic and land-use scenario, it is necessary to analyse the existing agricultural land-use pattern and suggest viable alternatives considering location-specific conditions to sustain the existing agricultural productivity and soil-environmental health.

Identifying shift in agro-climates

In recent years, along with increased weather variability, lots of changes is being observed in the pattern of the temperature and rainfall distributions. This needs to be investigated and changes to be identified both in qualitative and quantitative terms. The shifts in the climatic factors may have advantages and disadvantages to that region wrt existing agricultural systems. If its advantageous, one can harness its potential, else suitable alternate interventions can be explored to reduce the risk involved and enhance the crop productivity.

Harnessing solar radiation potential

Crop production is an exploitation of solar radiation. On average 75% of the incident radiation is absorbed by the crop canopy, 15% is reflected and 10% is transmitted. There are several environmental factors that regulate the photosynthesis rate. It is a known fact that photosynthesis is an inefficient process in the utilization of solar radiation. It was estimated that the maximum efficiency of the photosynthetic process in the utilization of total incident solar radiation is around 7% only. Hence, in this regard, agrometeorological intervention would pave the way to increase crop Radiation Use Efficiency (RUE). Location-specific experiments are required to quantify the RUE for the popular varieties of major crops and this would help in the selection of cultivars with high RUE to harness the incident solar radiation effectively.

Ensuring better crop establishment in rainfed regions through sowing decisions

Optimum sowing/planting time decides the success of rainfed crop production as late sowing/planting badly affects the production as well as sowing in the next season. Inter-annual fluctuation at the start of crop growing season is the major challenge for rainfed farming and precise information on this aspect is very essential. Onset of crop growing season is a novel concept to delineate any region to assess the optimum time to go for sowing. Similarly, Dynamic Crop Weather Calendar, a decision support system can be used to identify the best time of sowing, for irrigation application and also the amount of irrigation.

Future scope of work

Despite of the advances in agricultural technologies, agricultural production system is still largely dependent on weather. Because of the challenges of increasing climate variability, associated extreme events, and climate change to agricultural production, research and services related to agrometeorology are more important than ever. In addition to better agroclimatic characterization, the following agrometeorological interventions will also help in reducing the risks involved in agriculture

- Preparing for anticipated climate
- Establishing location specific crop-weather relationships
- Crop-weather-pest/disease interaction studies
- Opportunities in Agromet Advisory Services
- Use of geo-spatial information
- Use of sensors/ AI/ IoT technologies
- Utilization of crop simulation models

Carbon Footprint and Aggregation of an Alfisol in Response to Different Tillage and Maize (*Zea mays* L.)/ Cowpea (*Vigna unguiculata* L.) Intercrop

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Introduction

Soils are vital pools of carbon (C) in the terrestrial ecosystems. It was estimated that a global total of 2,500 Gigaton (Gt) of C is stored in soil, 3.3 times the amount of C stored in the atmosphere and 4.5 times the amount of C stored in the biotic pool (Lal, 2004). On a global scale, 75 Petagram (Pg) of C has been emitted annually, with a large portion of the emission from agriculture land (Lal, 2004). The development of low-carbon agriculture systems to store as much C as possible in soil is considered an urgent measure (Fedoroff *et al.* 2010). A key strategy in reducing CO_2 emissions from agricultural soil is to adopt improved farming practices such as conservation tillage and intercropping in crop production (Gan *et al.* 2011). Therefore, tillage practices should be evaluated in terms of their effect on soil physical properties. Intercropping, on the other hand has been widely adopted in many parts of the world as a means of increasing crop productivity (Chai *et al.* 2013); and cropping intensification is recognized as a key farming strategy in reducing global warming potential (Gan *et al.* 2012). The adoption of intercropping has significant advantages on carbon sequestration than conventional sole cropping (Asgedom and Kebreab, 2011). Carbon footprint (CF) of a product is defined as the sum of greenhouse gas emissions and removals in a production system, expressed as CO_2 equivalents and based on a life cycle assessment using the simple impact category of climate change (ISO/TS, 2013). Assessing the CF of crop production could provide insights into its contribution to climate change and help identify possible greenhouse gas mitigation options (Cheng *et al.* 2015). Concerns about greenhouse gas (GHG) emissions and their effect on global warming have inspired the quantification of the carbon footprint, i.e., the contribution to GHGs in carbon equivalents (CE) of many human activities (Hillier *et al.* 2009). The CF of crop production can be quantified considering the overall GHGs emissions from agricultural inputs used for crop production including farm machinery in cause of production (Adler *et al.* 2007). Therefore, this study evaluated short-term carbon footprint

(CF) in a production system to assess the impact of climate change and improvement in soil aggregation following the application of different amendments.

MATERIALS AND METHODS

Experimental site

This experiment was located at Directorate of University Farms in the Federal University of Agriculture, Abeokuta, Nigeria (Latitude 7.12° N and Longitude 3.23° E). This area is located within the transition zone of the sub-humid tropical forest to the south and the derived savannah to the northwest. The soil at this site (Table 1) is well-drained sandy loam with gravelly sandy clay loam in the subsurface derived from the basement complex; and classified as an Oxic Paleustalf.

Experimental treatment and land preparation

The experiment which was conducted in the planting season of the year 2018 was a split-split plot fitted into a Randomized Complete Block Design with tillage as the main plot, cropping system as sub-plot, and amendments as the sub-sub plot replicated three times making a total of eighty-one (81) plots. The variety of maize planted was Oba Super-2 hybrid, while that of cowpea was IT10K-836-4. Amendments were NPK + Urea and organo-mineral fertilizer.

Aggregate size distribution and stability

Aggregate size distribution and stability were measured using the wet-sieve method of Kemper and Rosenau (1986) in sieve sizes 5.66mm, 4.0 mm, 2.0mm, 1.0mm, 0.5mm, and

Table 1: Physio-chemical properties of the site and organo-mineral fertilizer

Parameters	Value
Sand (g kg^{-1})	788.0
Clay (g kg^{-1})	169.2
Silt (g kg^{-1})	42.8
Textural class	Sandy Loam
OC (g kg^{-1})	16.3
TN (g kg^{-1})	0.62
Av. P (mg kg^{-1})	6.21
K (cmol kg^{-1})	0.50
Ca (cmol kg^{-1})	0.26
Mg (cmol kg^{-1})	0.42
Na (cmol kg^{-1})	0.45
Organo-mineral Fertilizer: N (g kg^{-1})	20.0
P (g kg^{-1})	6.5
K (g kg^{-1})	57.0
OC (g kg^{-1})	88.1

0.25mm. The soil retained in each sieve were oven-dried and weighed. Mean weight diameter (MWD) was determined using the following relationship:

$$MWD = \sum Xi\, Wi \quad \text{... (1)}$$

Where the diameter of each is size fraction (mm) andis the proportion of the total sample weight (WSA) in the corresponding size fractions after removing stone weight. Higher value of mean weight diameter indicates less erodible soil (Piccolo *et al.* 1997).

Total carbon and nitrogen

Total soil organic carbon was determined using acid dichromate wet-oxidation procedure of Walkley and Black (1934) adapted by Nelson and Sommers (1996); while Total Nitrogen was determined by Kjedahl analytical method as described by Bremmer and Mulvaney (1982).

Assessment of climate change impact

Climate change as influenced by the management practices, i.e., tillage, cropping system and amendments, was evaluated by carbon sequestered below the ground and greenhouse gas emissions in the whole life cycle of the test crops, i.e. carbon footprint (CF).

Carbon sequestration

This study determined carbon sequestration from the difference between total elemental and control stock (Adesodun and Odejimi, 2010).

Greenhouse gas emissions and carbon footprint

Different versions of the carbon footprint concept have been represented in the literature (Wiedema et al. 2008; Dubery and Lal 2009). Dubey and Lal (2009). The total GHGs emissions in carbon equivalents through material added and from tillage operations performed in a single whole cycle of crop production were assessed (Hillier et al. 2009) as:

$$E = \sum AI \times EF \quad \text{... (2)}$$

Where AI denotes the amount of an agricultural input (kg/ha) and EF is emission factor of a unit of input material (kg CE/kg). Total GHGs emissions were determined as the sum of the input factors (AI_i) multiplied by the appropriate carbon emissions conversion coefficient ($E\boldsymbol{i}$) for each factor plus N_2O emissions GHG_{N2O} from croplands (Haina *et al.* 2015).

Direct N_2O emissions (E_{N2O}, kg CE/ha) induced relative to inputs were estimated as:

$$E_{N2O} = N_{Applied} - TN \times EF_{N2O} \times 44/28 \times 298 \times 12/44 \quad \text{... (3)}$$

Where N represents the chemical fertilizer-N applied (%/ha); TN is the total nitrogen measured (%); EF_{N2O} is the emission factor of N_2O emission induced by N fertilizer application (kg N_2O-N/kg N fertilizer); 44/28 is the molecular weight of N_2 in relation to N_2O; 298 is net global warming potential (GWP) of N_2O in a 100-year horizon and 12/44 is the molecular weight of CO_2 in relation to CE. According to IPCC (2006), EF_{N2O} is estimated as 0.01 for dry cropland and 0.003 for submerged rice paddy (Cheng *et al.* 2015).

Also, it was shown by Ma et al. (2012) and Hillier et al. (2009) that 75% of total Carbon Footprint from crop production resulted from N inputs. Therefore, using urea as N-fertilizer source and since carbon contained in the urea is often released as CO_2 during hydrolysis (IPCC, 2006), emissions of CO_2 from urea-based N fertilizer were calculated according to Ma *et al.* (2012) as:

$$CO_2\,eq. = (Q_{Urea} - OC) \times 12/28 \times 44/12 \qquad ... (4)$$

Where CO_2 eq. is emissions of CO_2 from urea application (kg CE ha^{-1}); Q is the quantity of urea-based fertilizer applied (%/ha); OC is the measured organic carbon in soil (%); 12/28 is the ratio of C to N; and 44/12 is conversion of C to CO_2.

Total CF (kg CE/ha) of crop in a single cropping season in terms of land use were assessed by summation of individual GHG emission as:

$$CF = \sum Ei \qquad ... (5)$$

Therefore, the CF in terms of grain yield measured from individual plots in the whole life-cycle of the maize-cowpea production system expressed as kg CO_2 eq kg^{-1}grain was calculated as:

$$CF = \text{Total GHG emissions (kg } CO_2 \text{ eq ha}^{-1}) / \text{Grain yield (kg ha}^{-1}) \qquad ... (6)$$

Grain yield data is not presented in this paper.

Data Analysis

Data collected were subjected to analysis of variance (ANOVA), and the significant means were separated using the least significant difference (LSD) at 5% probability level.

RESULTS AND DISCUSSION

Aggregate size distribution and stability

Soil aggregation by aggregate size distribution and mean-weight diameter (MWD) as affected by tillage, cropping system and amendments are represented in Table 2. The results show improvement in plots under no-tillage (NT) over minimum- and conventional tillage. Higher aggregation was observed in plots planted with maize and cowpea under NT with corresponding stable aggregates measured by mean-weight diameter which was 1.267 mm with amendment with OMF and 1.100 mm with application of NPK under cowpea and maize production (Table 2). The general trend with the aggregation and stability followed NT > CT>MT; higher values of < 0.25 mm microaggregate fraction indicate disaggregation of this tropical soil with tillage.

Carbon and nitrogen contents and stocks

Significant difference ($P \le 0.05$) in soil organic content (SOC) was observed in NT, MT, and CT tillage with highest SOC in NT plots and least under CT (Table 3). This may be due to gradual accumulation of SOM at the soil surface of NT as reported by Shi *et al.* (2012) who observed that organic carbon concentration was higher in soils under NT than under CT. The TN contents with treatments applied followed same trend with OC. The amount of SOC and TN that exist in any given soil is determined by the balance between the rate of organic carbon (OC) input and output carbon dioxide (CO_2) release into the atmosphere

Table 2: Soil aggregate distribution and mean-weight diameter relative to treatments

Tillage	Amendment	Cropping System	Aggregate Sizes (MM)					
			5.56-2	2.1	1-05	0.5-0.25	<0.25	MWD
NT	Control	Cowpea	13.67	18.60	19.87	12.07	35.80	0.900
Maize		Intercrop	13.53	18.60	20.60	13.47	33.80	0.900
		19.60	18.13	19.87	11.73	30.67	1.033	
	NPK	Cowpea	20.33	19.60	18.40	12.93	28.73	1.100
		Intercrop	13.60	24.80	18.67	12.60	30.33	0.933
		Maize	21.80	18.40	18.93	12.33	28.53	1.100
	OMF	Cowpea	18.73	17.87	20.73	14.80	27.87	1.033
		Intercrop	17.67	16.33	18.53	12.93	34.53	0.967
		Maize	24.53	24.33	15.00	10.73	25.40	1.267
MT	Control	Cowpea	9.53	15.27	19.20	15.60	40.40	0.733
		Intercrop	10.13	14.00	19.87	14.80	41.20	0.733
		Maize	7.87	15.73	21.60	18.67	36.13	0.700
	NPK	Cowpea	6.47	20.07	22.07	18.13	33.27	0.733
		Intercrop	6.07	15.27	19.07	20.53	39.07	0.600
		Maize	5.60	14.00	21.20	23.67	35.13	0.600
	OMF	Cowpea	6.13	14.73	21.67	19.80	37.67	0.633
		Intercrop	7.80	15.60	21.33	17.20	38.07	0.700
		Maize	6.87	13.73	20.73	19.73	38.93	0.633
CT	Control	Cowpea	11.80	21.87	20.07	13.47	32.80	0.867
		Intercrop	8.07	18.00	19.07	10.73	44.13	0.700
		Maize	11.07	19.27	21.67	15.47	32.53	0.800
	NPK	Cowpea	12.67	16.20	20.73	14.93	35.47	0.833
		Intercrop	11.47	13.93	23.67	16.93	34.00	0.800
		Maize	12.07	18.33	21.40	14.20	34.00	0.833
	OMF	Cowpea	11.47	17.27	21.53	17.53	32.20	0.833
		Intercrop	13.47	16.73	23.87	14.53	31.40	0.800
		Maize	12.53	15.47	19.60	16.40	36.00	0.800
LSD $p \leq 0.05$:								
T			**	*	*	**	**	**
A			ns	ns	ns	*	*	ns
CP			ns	ns	ns	ns	*	ns

NT = No-till, MT = Minimum tillage, CT = Conventional tillage, T = Tillage, A = Amendment, CP = Cropping system, MWD = Mean-weight diameter, OMF = Organo-mineral fertilizer.

Table 3: Total organic carbon and total nitrogen contents and sequestered C and N.

Treatments		TOC ($g\ kg^{-1}$)	TN ($g\ kg^{-1}$)	C-seq* ($kg\ m^{-2}$)	N-seq* ($kg\ m^{-2}$)
Tillage	NT	21.39	1.835	0.66	0.110
	MT	15.80	0.773	-0.83	-0.012
	CT	17.09	0.798	-0.45	0.049
LSD $p \leq 0.05$		2.721*	0.1548**	0.827*	0.045**
Amendment	Control	19.08	1.074	0.00	0.000
	NPK	17.68	1.145	-0.22	0.244
	OMF	17.52	1.187	-0.40	0.049
LSD $p \leq 0.05$		ns	ns	ns	ns
Cropping System	Cowpea	17.35	1.065	-0.27	0.006
	Intercrop	17.25	1.159	-0.42	0.017
	Maize	19.68	1.182	0.08	0.026
LSD $p \leq 0.05$		ns	ns	ns	ns
T X A		2.350	ns	ns	0.039*
T X C-sys		ns	0.1337**	ns	ns
A X C-sys		ns	ns	ns	ns
T X A X C-sys		ns	ns	ns	ns

* Depth 0-15 cm, T = Tillage, C-sys = Cropping system, A = Amendment

(Adesodun and Odejimi, 2010). Carbon-Nitrogen sequestration was estimated from the soil total organic carbon (TOC) and total nitrogen (TN) stocks, where TOC and TN stocks from the control plot were used as baseline. According to Tan and Lal, (2005), positive value represents accretion while negative value indicates less OC and TN indicating C-N release as greenhouse gasses. It was observed that 0.66 kg m^{-2} C and 0.1102 kg m^{-2} N were sequestered under NT tillage while MT and CT sequestered less OC and TN showing reduction in the storage of C-N with consequent release into the atmosphere in the form of CO_2 and N_2O. The contents of C-N stored were least in plots treated with NPK and OMF; whereas plots planted with maize had highest C-N than other cropping system (Table 3). Under tillage, OC and TN stocks significantly ($P \leq 0.05$) followed NT > CT > MT. Results from this study agrees with Denef *et al.* (2004) who reported that soils under NT generally contain larger SOC pool than soils tilled conventionally.

Effects of Treatments on carbon-dioxide and nitrogen-oxide emissions

Tillage significantly ($P \leq 0.05$) affected CO_2 and N_2O emission with least emissions observed in NT plots (Table 4). Specifically, the highest N_2O emission (22.535 kg CE ha^{-1}) and 2.062 kg CE ha^{-1} for CO_2 were observed under CT with least N_2O (22.408 kg CE ha^{-1}) and CO_2 (1.373 kg CE ha-1) in no-tillage plots. With amendments, emissions of CO_2 and N_2O were highest with the addition of chemical fertilizers, i.e., NPK and urea followed by OMF treatment compared to control plots. Under the cropping system, the highest emission of 31.655 kg CE ha^{-1} and 2.869 kg CE ha^{-1} were observed in intercrop plots for N_2O and CO_2 respectively (Table 4).

Carbon Footprint as affected by treatments

The carbon footprint (CF) indicates total amount of GHGs, particularly CO_2 and CH_4, generated by our actions. Results from this study showed the highest CF was observed in conventional tillage (0.040 kg CO_2 eq ha^{-1}), followed by MT (0.027 kg CE ha^{-1}) and least (0.013 kg CE ha^{-1}) in no-tilled plots (Table 5). The highest release of GHG, i.e. high CF, was observed in plots amended with chemical fertilizer than with organo-mineral fertilizer. The effect of cropping system followed cowpea > intercrop > maize. The increase in CF with chemical fertilizer can be attributed as reported by Cassman *et al.* (2013 that application of nitrogen in inorganic fertilizer form is not always utilized efficiently by crops.

Conclusion

This study showed that stability of this soil was better improved with no-tillage than conventional tillage and minimum tillage. Application of organo-mineral fertilizer improved the soil aggregate stability than the application of chemical fertilizer, while planting of sole maize aggregated the soil more than sole cowpea or intercrop of maize and cowpea. The results also showed that greenhouse gas emission was lowest in no-tillage system. Application of chemical fertilizers significantly increased total GHG emission than organo-mineral fertilizer, while carbon footprint (CF) was found to be least under no-tillage system. Planting of sole cowpea led to higher CF than sole maize and intercrop of maize and cowpea. Finally, for this fragile tropical soil, it was concluded that no-tillage and minimum tillage with use

Table 4: Greenhouse gases emissions relative to treatments applied.

Treatment		CO2 emission (kg CE ha-1)	N2O emission (kg CE ha-1)
Tillage	NT	1.373	22.408
	MT	1.903	22.531
	CT	2.062	22.535
LSD p≤0.05		0.346**	0.0135**
Amendment	Control	0.000	0.000
	CHF	4.249	36.531
	OMF	1.088	30.942
LSD p≤0.05		0.346**	0.0135**
Cropping system	Cowpea	0.000	15.995
	Intercrop	2.869	31.655
	Maize	2.468	19.824
LSD p≤0.05		0.346**	0.0135**
T X A		ns	0.0116**
T X C-sys		0299*	ns
A X C-sys		0299**	0.0116**
T X A X C-sys		ns	0.0202*

T = Tillage, C-sys = Cropping system, A = Amendment, CHF = NPK (15:15:15) + urea

Table 5: Carbon footprint relative to the treatments.

Treatment		CF (Kg CE ha^{-1})
Tillage	NT	0.013
	MT	0.027
	CT	0.040
LSD p≤0.05		0.021*
Amendment	Control	0.000
	CHF	0.044
	OMF	0.037
LSD p≤0.05		0.021*
Cropping system	Cowpea	0.055
	Intercrop	0.020
	Maize	0.005
LSD p≤0.05		0.021*
T X A		0.018*
T X C-sys		0.018**
A X C-sys		0.018**
T X A X C-sys		0.032*

T = Tillage, C-sys = Cropping system, A = Amendment, CHF = NPK (15:15:15) + urea

of organo-mineral fertilizer are better options for maize and cowpea production with less carbon footprint, and consequent reduction of greenhouse gases into the atmosphere.

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Soil Erosion Control is Key to Sustainability through C-Sequestration and Climate Resilience

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Introduction

Soil erosion is one of the ten major soil threats identified in the 2015 Status of the World's Soil Resources report. It is defined as the accelerated removal of topsoil from the land surface through water, wind and tillage.Soil erosion is one of the most dominating factors of land degradationundermining the livelihoods and food security of about 3.2 billion of people, especially small and marginal farmers, landless and pastoralists. Globally, about 24.0 billion tonnes of fertile soil is lost annually through water erosion (FAO, 2011) resulting 5% reduction in a loss of total global net primary productivity (IPBES, 2018).Soil erosion in a natural form may be attributed for the development of some of the world's most productive land but the excessive soil loss resulting from poor land management has serious implications for crop productivity and food security, whichcallsforsustainableuseofoursoilresource.Rampant soil erosion is one of the most serious contemporary environmental problems (Amundson*et al*., 2015; Mandal et al, 2020)resulting indesertification, a decrease in agricultural productivity, sedimentation of waterways and water bodies, and ecological collapse due to loss of the nutrient-rich upper soil layersand therefore responsible for the extreme poverty in many places. About 1/3rd of global soilis already degraded and over 90% could become degraded by 2050 (FAO and ITPS, 2015; IPBES, 2018).With 84-85 percent, soil erosion is the main contributor (Blanco and Lal, 2010). Globally the erosion-inducedloss of fertile soil from world agricultural systems to the tune of more than 36 billion tonnes each year (IAEA, 2023) poses a great existential challenge. The land degradation processes are particularly severe in the hunger belt swathed around the equator comprising ecosystems of the tropical and sub-tropical countries (Falkenmark, 1984).In India, 120.72 million ha is subjected to various forms of land degradation, with water erosion contributing the most spread of 68.4 percent (82.57 million ha) of the total degraded lands (ICAR,2010). Region-wise statistics show that the central region is the worst affected of all (59 % of its total area), followed by North-Eastern and Southern regions.Besides the loss of soil fertility, soil erosion can affect the infiltration, storage, and drainage which can lead to up to 50 percent loss in crop yields.India as a whole loses 15.7% of its total production of cereals, oilseed and pulse crops, equivalent to Rs. 292.03 billion as per the 2015-16 prices (Sharda and Dogra, 2013).

The preferential loss of organic carbon, nutrients, and finersoil particles due to water erosion has been well documented in terms of enriched sediment (Kumar et al., 2023; Kumar et al., 2014). The total cost of replacement of lost carbon and nutrients is estimated at about Rs. 2,000/- per hectare per year(Mandal et al.,2021).About60-70% of eroded carbon gets redistributed over the landscape 10% is transported to the ocean and about 20-30% of carbon transported by erosion is emitted to the atmosphere causing further climate change (Lal, 2003).

Climate change is further posing a great challenge and in the absence of measures to reduce degradation, areas of land degradation due to water erosion in likely to increase (Olsson et al., 2019). It is projected that a 1% increase in rainfall intensity may increase the rainfall erosivity by 2.0% and soil loss from cropland by 1.5% (Sharda and Ojasvi, 2006; Ojasvi et al., 2006).This is high time for researchers and policy makers to work hand in hand for controlling soil erosion to reduce the impact of climate change. Plenty of experimental evidences of averting land degradation by controlling soil erosion resulting into carbon sequestration and ecosystem services recovery accentuate the need of the coordinated efforts at national level involving all the stakeholders. The present manuscript gives a brief account of the erosion problem, past experiences and success, research needs and strategies for making soil erosion control a national mission, and people's movements for harnessing carbon sequestration potential.

Erosion-induced land degradation and losses:The gross erosion of the country is estimated as 5.11 ± 0.4 Gt yr^{-1} or 1559 t km^{-2} yr^{-1}, out of which 34.1 ± 12% of the total eroded soil is deposited in the reservoirs, 22.9 ± 29% is discharged outside the country (mainly to oceans), and the remaining 43.0 ± 41% is displaced within the river basin (Sharda and Ojasvi, 2016). Among different land resource regions, the highest erosion rate occurs in the black soil region (23.7–112.5 t ha^{-1}) followed by Shiwalik region (80 t ha^{-1}), North-Eastern region with Shifting Cultivation (27-40 t ha^{-1}) and the least in North Himalayan Forest region (2.1 t ha^{-1}).

SOC and Nutrient Loss: Runoff carries the finer soil particles and nutrients along with it in dissolved form or sediment bound. If continued unabated it results in loss of soil fertility and productivity. The associated loss of soil organic carbon and nutrients has several ramifications including increased emissions, pollution in water bodies, and overall loss of ecosystem services.Mandal et al., (2012) reported a SOC enrichment ratio of sediment in the range of 1.45-2.65 from sandy loam soil in the sub-humid northwest Himalayas. The SOC enrichment ratio of 1.62 - 3.12 was reported from the sandy loam soil of semiarid regions of India under different land configurations and management (Kumar et al., 2023). A higher OC enrichment ratio from the soil containing low SOC has been reported by Holz and Augustin (2021). The mean seasonal organic carbon loss from different slope lengths, slopes, and managementin the range of 19.9 to 61.7 kg ha^{-1},andnitrogen loss in the range of 5.1 to 13.9kg ha^{-1}has been reported (Kumar et al., 2023). SOC loss of 14.8 - 54.0 kg ha^{-1} under pearl millet has also been reportedby Kumar et al., 2014. These plot scale data cannot be extrapolated at the landscape and national level but nevertheless, it indicates the erosion-induced displacement and loss of organic carbon.

Soil loss resulting in loss of 5.37 to 8.40 million tonnes ofnutrients in India has been reported by Sharda and Ojasvi, 2016. Estimation of erosion-linked N, P, K, and S displacement of4.4- 9.6, 0.39-2.3, 4.4- 8.7 and 1.27-1.65 million tonnes amounting to the corresponding monetary loss of 135 -293, 18.5-83.2, 173 and 58.9-77.9 billion rupees (2020 price), respectively (Kumar et al., 2020)

Production loss: The erosion induced loss in production often gets camouflaged by the increased level of inputs and improvement in technology and practices. The estimates of production loss due to water erosion by various agencies varies widely. The production and monetary losses due to water erosion computed for 27 major cereal, oilseed and pulse (COP) crops based on crop and agro-climatic region-specific productivityloss factors evolved by utilizing experimental data (Sharda *et al.*, 2010a; Sharda *et al.*, 2010b; Sharda and Dogra, 2013)reveals that country as a whole loses about 15% of its total productionamounting to Rs. 292 billion in monetary terms (2015-16 prices).Production loss of 1.40 % in Punjab and Haryana states located in low productivity loss-prone alluvial Indo-Gangetic Plains to 41.0 % in the erosion-prone north-eastern Himalayan state of Nagaland was estimated. Cereals were the major contributors in terms of production (66.0 %) andmonitory (44.0 %) loss respectively, followed by oilseeds (21.0 % and 32.0 %, respectively) and pulses (13.0 % and 24.0 %, respectively).

Siltation in reservoir: As per CWC records India has 5745 large dams, of which 5334 are completed and operational while 411 are under construction stage (PIB, 2022).Erosion in the catchment area often leads to sedimentation in the reservoir. The total sediment trapped in the reservoirs was estimated at 1679 M m^3 yr^{-1}, resulting in the average annual capacity loss of the reservoirs of 1.04% with a range of 0.47 to 3.05% (Sharda and Ojasvi, 2016). Loss of gross storage capacity in the range of 0.50 % to 0.80 % per year in the case of larger dams with capacity varying from 51 to >1000 M m^3and0.80 % to >2.00 % per year for smaller dams of 1 to 50 M m^3 capacity.Pandey et al., (2014) reported 0.495% and 1.27% annual total storage loss and dead storage loss, respectively, due to sedimentation in Sardar Sarovar dam resulting to annual capitalized loss of 1069.7 to 1137 million rupees for loss in power generation and irrigated area under different scenario of rainfall.

Carbon Sequestration Potential in India

Indian soils are poor in organic carbon as most cropland soils contain extremely low levels of SOC concentration (0.2-0.5%). Though there are studies to suggest net sink potential of the soils in India, there are evidences also to indicate that increasing SOC is very challenging owing to tropical climate.Enhancing SOC in these soils can improve soil quality and productivity directly and indirectly. Reclamation of degraded soils and ecosystems and adoption of watershed management can enhance the terrestrial C pool, microbial population and soils net C sinks. Agro-forestry,conservation agriculture and other agro-ecological approaches are good options for carbon sequestration. The total potential of C sequestration in India is 77.9 to 106.4 Tg yr^{-1}, about 12.9% is through restoration of degraded soils, 45.6% through erosion prevention and management, 15.8% through agricultural intensification and 25.7% through secondary carbonates (Lal, 2004).

Evidence of gain due to erosion control: Realizing the importance of soil erosion, several initiatives were takenjust after independence remained at fore for several decade. Establishment of soil conservation institutes/organization at central level, soil conservation department at state levels indicated the foresightedness of the researchers and policy makers of the past in shaping future of the country. Vegetative and bioengineering measures for controlling soil erosion are very crucial for augmenting the living landscape to support a variety of ecosystem services. Soil erosion control on agricultural and includes application ofgood agricultural practices including, Minimum tillage, contour faring, mulching, conservation agriculture, residue incorporation, strip cropping, vegetative barrier besides a list of engineering and bioengineering measures including different type of bunding, trenching, terracing. Application of manure to improve soil physical conditions including aggregation, bulk density, infiltration and to reduce soil erosion by reduced soil erodibility have been reported (Masmoudi et al., 2020; Tulu, 2017;Kumar et al., 2014). After 10 years of minimum tillagea 19.2% highertotal organic carbon (TOC) in minimum tillage (MT) in comparison to CT was reported byPrasad et al., (2016).Highest growth of TOC is observed in case of application of rice straw along with NPK(Ghosh et al.,2021). Das et al., 2013 reported that about 10.2% of the added C was retained under different residue managed plots where ZT was adopted.Plot under zero tillage had about 28 % higher SOC in top 5cm layer. Bhattacharyya et al., (2009) reported 10.2% higher equivalent depth based-SOC in zero tillage than CT after 4 years of experimentations. Higher organic carbon (6.80 g/kg) content was recorded with the application of Sorghum Stover (Sharma et al., 2018).There isa large number ofstudies to support improvement in soil organic carbon as a result of residue incorporation, application of manure, green manuring, and practicing minimum tillage (Pathak et al.,2006; Hati et al., 2007; Srinivasarao et al., 2012; Bhattacharyya et al., 2012; Kumar et al., 2014) which can be interpreted as reduced soil erodibility. Therefore, these practices are effective in reducing soil erosion and soil carbon sequestration.Gain of 433 kg C ha^{-1} yr^{-1}in SOC under the application of 10 t ha^{-1}of FYMon sandy loam soil of semiarid reason as compared to the control was attributed to the high biomass addition, reduced soil erosion, and improved soil physical condition (Kumar et al., 2014). Reduction in soil erosion was attributed to the improved soil physical conditions and higher canopy coverage. Kurothe et al., (2014) reported lower soil erosion (37.2%)and higher SOC content under NT after 7 years of treatment.Water-stable macro-aggregateswere also significantly greater under NT. Stubble mulch farming practices resulted in reduced runoff, soil erosion, and increased soil OC.The use of soil and water conservation (SWC) technologies in river basins is proven to result in reduced erosion and sediment loads in water bodies.

Need to Control Soil Erosion

Soil conservation is a must for survival and sustainability. There are evidences to suggest the decline in society and civilization with a decline in soil conditions. Once soil is lost it is lost for many generations. The dilemma is that most soil conservation measures are preventive in nature and even if you ignore them for a while the impact is not clearly visible even though there is a definite decline in potential. Under this scenario, it becomes difficult for researchers to persuade landholders and policymakerstoinvest in SWC technologies. Some of the SWC measures are cost-intensiveand therefore not adopted by farmers without support from Govt sponsored program. Even the intangible benefits accrued out of the conservation measures though accounted for, are not appreciated in developing and less developed world where things of immediate necessity are not met. Despite of the challenges, India has set an ambitious target of achieving land degradation neutrality in 26 million hectares of land by 2030. Considering the need of arresting the recent trend of degradation, the actual target becomes 30 million hectares. Such initiatives foster hope that land restoration can not only help mitigate climate change through carbon sequestration but also improve rural livelihoods and spur growth by renewing the land's productive capacity.

Two ways approach is required to achieve the objectives of the said mission. The first one includes strengthening the Institutional mechanism and revamping the conservation program incorporating learning from past experiences the second includes the promotion of low-cost, production oriented doable technologies at farmer level. Conservation treatment on all lands is neither practical nor possible therefore the identification of high erosion risk area for priority treatment is a must.

Identifying erosion risk area: Soil erosion is a natural process and can't be paint-brushed as harmful. It has had its own advantages and role in developing great productive plains including the great Indo-Gangatic plain. Land can afford to lose some amount of soil but if it goes beyond a certain limit it is bound to have negative onsite and offsite effects. A Soil loss tolerance limit map of India has been prepared by Mandal and Sharda, (2011). The great plains of India are better placed with higher soil loss tolerance value (12.5 t $ha^{-1}yr^{-1}$) followed by coastal plains. The Peninsular India and Peninsular plateau are of utmost concern because a considerable area can only afford soil loss ranging from 2.50 to 5.00 t $ha^{-1}yr^{-1}$. About 42.8% of TGA can tolerate a soil loss of more than 12.5 t $ha^{-1}yr^{-1}$ as the remaining about 57.2% area had T-value ranging between 2.50 and 10.0t.$ha^{-1}yr^{-1}$including about 7.40 % area with T-value of 2.50t.$ha^{-1}yr^{-1}$. The area with a T value of 2.50 t.$ha^{-1}yr^{-1}$ is most sensitive from a conservation point of view as due to shallow soil depth and poor quality, it is highly vulnerable to loss of crop productivity if erosion exceeds the tolerance limit. Annual crops grown in rainfed shallow soils are highly susceptible to droughts, the frequency of which has increased in the recentyears. There is need to develop high resolution new data base on soil erosion and land degradation.Though the statistics on land degradation in Indian in periodically generated by the centre of Indian Space Research Organization in form of Desertification and Land Degradation Atlas of India but the lack of cause-and-effect relationship makes it difficult to use the map for remedial action. With the increased availability of multiple sensors, remote sensing data, and drone-based sensors, there is a chance of developing a methodology for periodic and real-time monitoring and identification of soil erosion hot spots.

Scope of carbon sequestration by controlling erosion: Erosion induced carbon loss has been reported by scientific community mainly because of loss of onsite ecosystem services, however the carbon built up in the form of sequestration as a result of arresting soil erosion has been rarely reported.

Strategy to Control Soil Erosion at National Level

- Design criteria of engineering and bioengineering measures need to be relooked in light of climate change projections.
- The knowledge gap prevailing among the stakeholders needs to be bridged through a comprehensive capacity-building programme
- A video library "how to do" for different soil and water conservation measures needs to be developed for mass campaigns and easy adoption by farmers and other stakeholders.
- Incentivize the adoption of soil and water conservation technologies in a participatory mode as they initially require high investment and yield dividends are noted only in the long run.
- A mass awareness programme to sensitize farmers about the need of adopting conservation practices through mass media campaign and appeal by the popular public personalities.
- The seer success of the Swachchh Bharat Mission mainly though public appeal by the popular figure rekindles the hope of success of national mission of arresting soil erosion provided a supportive institutional mechanism is in place.
- Research and developmental institutions in the field of prevention of soil erosion should be strengthened adequately to generate data and technologies and capacity building across the country to achieve the objectives and goal of the policy.

Revamp and continuous watershed Programme: A revamped watershed programme still hold key for sustainable land management for food security and environmental restoration. Watershed programme has gone through several modifications gradually putting more emphasis on participatory component, livelihood activities and micro enterprises. However, an impression of no such visible success has been created mainly because its success is compared with the irrigated system despite the huge investment gap. Ecosystem generated from the watershed project especially the intangibles are rarely accounted. Averting or restricting land degradation often does not give 1 to 1 tangible return however the cost of inaction is much more than action.

Conclusions

India, a resource poor country, having over-dependence on natural resources can't afford to ignore the ongoing rate of soil erosion. It is the duty of the scientific fraternity to make the policymakers understand the preventive nature of the majority of soil and water conservation measures along with the importance and value of intangible benefits. There are good numbers of experimental evidences suggesting carbon movement and loss through soil erosion and improved soil carbon through good agricultural practices that arrests soil erosion. Identification of soil erosion hotspots and its periodic monitoring using space science tools is crucial for prioritizing treatment plan. Though the role of Institutions and government organization is very important mainly because of the high investment required in many

Institutional approach

Problem Assessment

- Updating erosion map and statistics using state of art technology and high resolution data
- Long term monitoring of erosion and hydrological data
- Use of simulation models for erosion estimation

Priority area identification

- Update priority map using the updated soil erosion data

Revamped watershed programme

- Incorporate Key drivers of success and participation
- Increase budget limit
- Stop comparison with irrigated area as cost involve is about 1/20th
- Strengthen linkage with Panchayat Institutions

Human resource development

- Upgrade institutional setup for training and capacity building

Mechanism of mid term correction and impact analysis

- Update indicators
- Account intangible benefits
- Bench mark data a must

Promoting SWC for Voluntary Adoption

Inventorize low cost doable production oriented technology

- Making list of low cost, production oriented, doable technologies for each village Panchayat

Brief on how to do (Video clip)

- Making a small video clip on "how to do at farmer's level" on every identified technology- most are common

Incentivize the adoption of SWC

- Incentivize the adoption, may be symbolic, honour by Panchayat Institutions, priority availability of input by PCAs, 0.2-0.5% lower interest on farm loan, priority purchase of produce by govt, Mandi or recognized buyers etc.

Mass appeal by popular leader, celebrities, public figures and religious leaders For adoption of SWC

- Success of Swachchh Bharat mission highlight the impact of mass appeal by popular figures and mass media
- Innovative farmers or farm union leaders may also be roped in for mass campaign

of the engineering measures, the target of controlling soil erosion at national level can't be achieved without a people's movement. With the existing capability of ICT and the reach of mass media, it is quite possible to make the reduction of soil erosion a mass movement just in the line of the Swachchh Bharat Mission. Repeated appeal by popular public figures, religious leaders, and celebrities can motivate the mass to adopt low-cost, production-oriented soil and water technology provided technical know-how is made available in form of the video clips. Incentivizing the adoption of SWC by the provision of reward through Panchayat level institution or through input, lending, and procurement agency will further drive the mass for voluntary adoption.

A revamped watershed management program with a higher cost limit of about Rs 50,000/- per hectare (1/5th of the cost of command area) need to be initiated keeping soil erosion control and carbon sequestration in focus. Climate resilience, carbon sequestration, productivity maintenance, flora and fauna diversity, land degradation neutrality, and achieving sustainable development goals are a few among several collateral benefits of adopting SWC technology thus deserve priority attention, promotion, and investment.

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The Value of Ecosystem Services from Sustainable Agricultural Practices in India: Implications for Re-purposing Agricultural Subsidies

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Introduction

Ecosystem services (ES) are the distinct array of the direct and indirect benefits that humans derive from the nature and play a pivotal role in supporting the well-being(Daily, 1997; MEA, 2005; de Groot et al. 2012). These services are typically categorized as provisioning, regulating, cultural, and supporting services (MEA, 2003). Provisioning services are the tangibleproducts obtained from ecosystems, and include the food, fiber, fuel, and ornamental resources. Regulating services are the benefits obtained by regulating various processes of the ecosystem, such as climate, water, diseases, and biological agents. Cultural services representthe non-material benefits to the peopleobtained from ecosystems through spiritual enrichment, cognitive development, recreation, and aesthetic experiences. Supporting services, on the other hand, are fundamental for the production of all other ecosystem services. Supporting services differ from other ecosystem services as their impacts on people are either indirect or extended over a period of time.

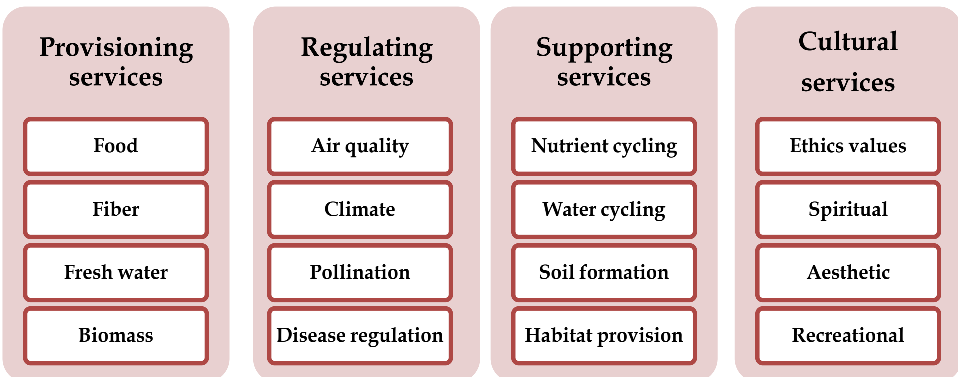

Fig. 1: Classification of ecosystem services (MEA,2005)

Ecosystem services, such as carbon sequestration, nutrient cycling, pest regulation and pollination, play a critical role inenhancing and sustaining the productivity of agricultural ecosystems. Hence, it is imperativeto conserve these services to promote resilience and long-term sustainability of agri-food systems.

Agroecosystems both provide and rely upon important ecosystem services, which often go unacknowledged and uncompensated due to market failures. In addition to the provisioning services, agriculture plays a crucial role in conserving some of the important ecosystem services including the carbon sequestration, watershed management, and landscape preservation. On the other hand, agriculture also receives some of the ecosystem dis-services, which have a negative impact, either decreasing productivity or increasing cost of production. The intensity of flow of supply of these ecosystem services primarily hinges on themanagement of agroecosystem and complex factors includingbiophysical interaction, ecological processes, climatic conditions, farming practices,and input choices.The brief flow ofecosystem services and disservices to agriculture is represented in Fig. 2.

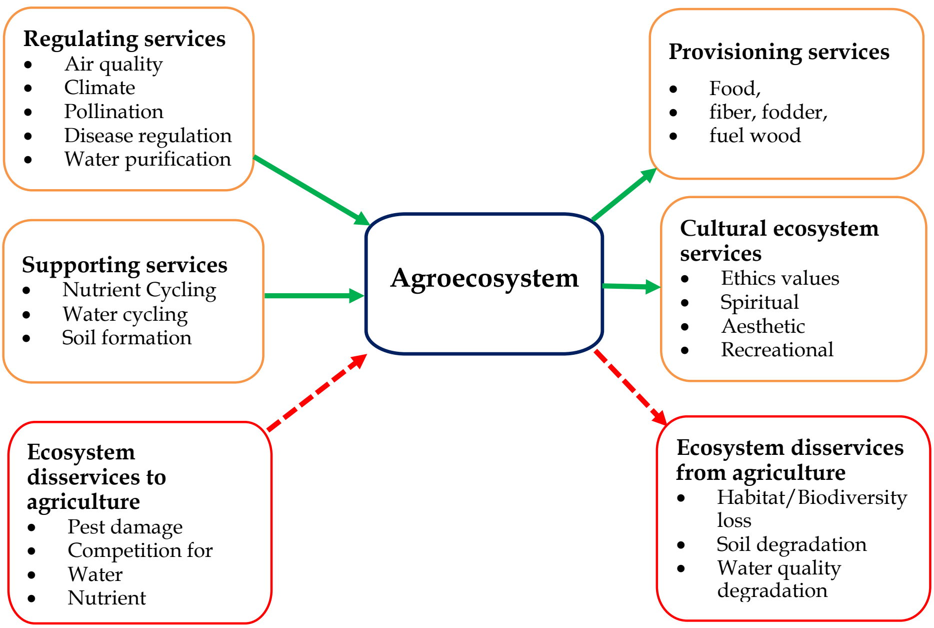

Fig. 2: Flow of ecosystem services and disservice to and from agriculture (Garbach et. al. 2014; Zhang et al.2007)

Although the adoption of unsustainable agricultural practices may lead to short-termincreases inthe provisioning services, it often comes at the cost of thedeterioration of other criticalecosystem services. Alternatively, agriculture also offersa huge opportunity to enhance ecosystem services without compromising yields through the adoption of sustainable agricultural practices.A plethora of studies acknowledged that improved agricultural practices have huge potential to enhance ecosystem serviceswithinthe agricultural landscape (Kumara et al. 2023).Unfortunately, the contribution of these practices to the conservation of ecosystem services is frequently underestimated, and farmers are rarely rewarded for these. This is because many ecosystem services are indirect benefits that are not directly visible;hence markets for such intangible goods do not exist in the real world.Consequently, farmers often go uncompensated for their essential environmental contributions to the society. Therefore, to address this issue and encourage the adoption of improved farming practices, it is imperative to assign a monetary value to the ecosystem services. These economic values serve as a foundation for the development of agri-environment payment systems and for making optimal decisions regarding the sustainable use and management of ecosystem services (Atkinson et al. 2012; de Groot et al. 2006).

Valuing ecosystem services: Approaches and methods

An economic valuation can be defined as the attempt to assign quantitative and monetary values to goods and services provided by environmental resources or systems, whether or not market prices are available (Lambert 2003).Historically, conventional economic analysis often overlooks the services provided by nature. Although the tangible natural resources used in the production process are valued at market prices, a significant array of intangible services are disregarded. This omission has led to massive destruction of nature and ecosystem degradation.Valuation provides a clear understating of the depletion of natural resources, itsassociated costs,and the contribution of ecosystems to the social and economic well-being.

Furthermore, valuation plays a crucial rolein allocating public investment forrestoration initiatives and incentivizingfarmers to conserve ecosystem services.Although a universally applicable approach to valuation frameworks remains elusive, the monetary approach, which combines qualitative and quantitative aspects into monetary terms, is the most widely adopted method in the valuation of ecosystem services.

The process of valuation of ecosystem services includes (i) identification of or mapping of ecosystem services, (ii) quantification, and (iii) assigning monetary value. Valuation of ecosystem services involves assigning economic or non-economic values to the benefits that ecosystems provide to humans. There exist several approaches and methods formonetizingecosystem services, each with its own strengths, limitations, and suitability for different contexts (Liu et al. 2010). The major valuation methods includethe direct market method, indirect or revealed preference method, and non–market or stated preference methods.The major valuation methods are depicted in Fig. 3.

Value of ecosystem services from improved agricultural practices

In India, few studies have attempted to assess the monetary value of ecosystem services derived from agriculture. The current valuation of agricultural ecosystem services

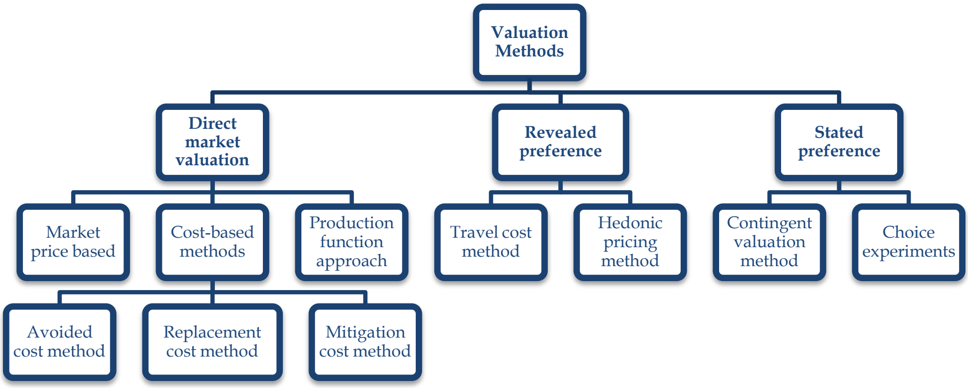

Fig. 3: Methods for valuation of ecosystem services (Adapted from Brander 2010; Legesse 2022)

is predominantly focused on assessing the monetary value of provisioning services. Additionally, the evidence on the positive impact on regulating and supporting ecosystem services in terms of improved soil and water conservation, biodiversity, water storage, soil retention, aquifer recharge, carbon retention, etc. are scattered and inconsistent (Palsaniya et al. 2012; Mondal et al. 2018). Therefore, the economic valuation of ecosystem services from agriculture is crucial for promoting and outscaling sustainable food production systems in India.

We undertook a comprehensive valuation of ecosystem services associated with six enhanced agricultural practices: (i) direct seeded rice (DSR), (ii) no-tillage in wheat, (iii) legumes, (iv) organic manure (farm yard manure), (v) integrated nutrient management (INM) and (vi) agroforestry. The primary ecosystem services, including the provisioning services (food), regulating services (carbon flow, nitrogen fixation, and water holding service), and supporting services (soil fertility and nutrient cycling) were considered for valuation in a meta-analysis framework. After excluding outliers, a total of 4726 pair-wise observations from 1104 studies were considered for the analysis. We employed both direct and indirect valuation methods, viz., market price, replacement cost, and benefit transfer methods to assign values to ecosystem services. The total value of the ecosystem service (TVE) provided by these improved agricultural practices is estimated as the sum of the value of tradable and non-tradable ecosystem services.

In direct-seeded rice (DSR), we observed a potential trade-off between yield and ecosystem services. Our findings indicatea significant reductionin yield(-10%) under DSR compared to conventional transplanted rice. However, DSR offers substantial environmental benefits, the value of such non-tradable services is estimated at Rs13,335/ha (Fig. 4.), accounting for 49% of the total value of ecosystem services.Further, findings revealthat no-tillage has both positive economic and environmental benefits over conventional tillage. The total economic value of the additional ecosystem services provided by no-tillwheat is estimated at Rs.7685/ha, of which non-tradable ecosystem services shareover three-fourths (Fig. 4.) representingthe positive externalities for the society.

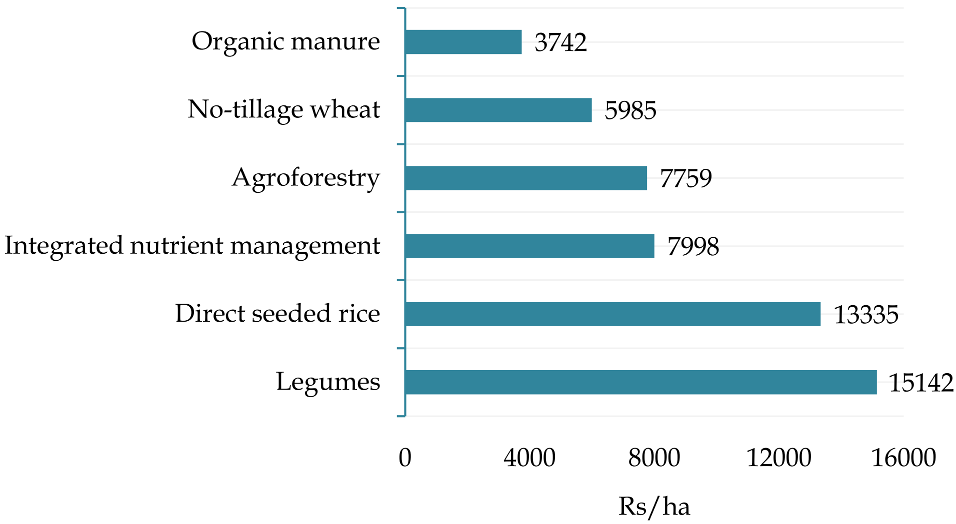

Fig. 4: Value of non-tradable ecosystem services (Rs/ha)

In addition to nutritional benefits, legume crops offer some vital non-tradable ecosystem services that contribute to sustainable development of agriculture. Legumes provide additional benefits worth Rs.32672/ha, of which 47% are accounted for by the non-tradable ecosystem services. The value of non-traded ecosystem services generated by legumes, including biological nitrogen fixation, carbon sequestration, soil fertility, water saving, and reduced greenhouse gas emissions collectively contribute Rs.15142/ha (Fig.4.). Farmyard manure (FYM) is a key component of sustainable agriculture due to its ability to improve soil biophysical properties and sequester carbon. However, our findings suggest that exclusive use of FYM leads to a yield reduction by 6.01% over chemical fertilizers. This decline is primarily attributed to slower nutrient release and insufficient nutrient supply to maintain desired crop production levels. As a result, the total economic value ecosystem services is negative and estimated at Rs.2001/ha. Nonetheless, FYM provides non-traded ecosystem services worth Rs. 3742/ha (Fig.4.). On the other hand, the evidence suggests that combining organic manure with inorganic fertilizers has the potential to sustain productivity while minimizing the negative impact on the environment (Darjee et al. 2022).

Besides improving yield, integrated nutrient management (INM) offers essential non-tradable ecosystem services,includingimproved NPK availability, carbon sequestration, and reducedirrigation water use compared to the chemical fertilizer application. The total monetary value of the ecosystem services of INM is estimated at Rs.23312/ha. Of this, the non-tradable services are estimated at Rs. 7998/ha (Fig.4.). Furthermore, despite the trade-off between crop yield and environmental services, the total value of non-tradable services from agroforestry system is estimated at Rs. 7759/ha. These services are not directly traded in markets. The high value of environmental benefits is mainly attributed to improvement in soil fertility, higher carbon sequestration, and reduction in loss of soil erosion.

Policy implications

Sustainable agriculture strategies are crucial to mitigate the climate change impacts on agriculture.Improved agricultural practices play a pivotal role in conserving vital ecosystem services without compromising food security. However, not all the agricultural practices generate win-win outcomes. Trade-offs between tradable and non-tradable ecosystem services may arise in some cases. Therefore, careful implementation and effective management strategy is necessary to minimize trade-offs and maximize win-win outcomes.

All the improved practices have huge potential to generatepositive environmental benefits compared to the conventional practices. Therefore, it is imperative to incentivize farmersfor the adoption of eco-friendly farm practicesthrough payment for ecosystem services (PES) schemes. One approach to achieve this is by repurposing existing agricultural incentives that currently support unsustainable patterns of production.In this context, repurposing fertilizer subsidies merits attention. The excessive and indiscriminate use of nitrogenous fertilizers has resulted in the degradation of natural resources and the environment. Therefore, gradual phasing out or reduction of fertilizer subsidies while providing income support that encourages farmers to adopt nature-based farming practices can be part of the repurposing strategy. Further,development of scientific and robust methodologies is essential to incentivize farmers and create markets for ecosystem services.

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Hydrological Impacts of Engineering Interventions in Watersheds

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Introduction

Soil and water are the most critical natural resources and physical bases for all life-supporting systems. These two resources are too precious for humanity as they meet all the needs and protect the environment and civilization. Land degradation has become a severe problem in India's rainfed and irrigated areas. India is losing a considerable amount of money from these degraded lands. A comprehensive study on the impact of water erosion on crop productivity revealed that soil erosion due to water resulted in an annual crop production loss of 13.4 Mt in cereal, oil seeds and pulse crops (Sharda *et al.*, 2010). Out of a total reported geographical area of 329 Mha of India, about 146.8 Mha are degraded by various factors. Water and wind erosion accounts for 70 % of the total degraded land and the remaining 30 % is due to salinity, acidity and other factors. Erosion due to shifting cultivation and cultivable wastelands are quite alarming. Annual soil loss in India is estimated as 5334 Mt along with these 8.4 Mt of major nutrients also lost (Prasad and Biswas, 2000). Annually, 2052 million tonnes of Soil is carried by rivers; out of this, nearly 480 million tonnes is being deposited in various reservoirs, resulting in 1-2 % loss of storage capacity per year (Dhruva Narayana and Rambabu, 1983). The annual sediment load inflow into many reservoirs ranges from 0.6 to 122.7 ham/ 10 000 ha. According to National Commission on Agriculture, reservoirs in India are silting up at a rate of three to four times faster than the designed rates.

The burgeoning population and its impact in every sphere of development, viz., agriculture, industry, and urbanization, depend primarily on water resources, leading to ever-increasing demands for water. Increasing water demand, over-exploitation of groundwater resources, and inefficiency in tapping surface water and harvesting rainwater created an imbalance, resulting in a shortage of water availability for sustainable food production and domestic usage. FAO has reported that the global water withdrawal increased from less than 600 km^3 $year^{-1}$ in 1900 to almost 4000 km^3 $year^{-1}$ in 2010. Further, it is assessed that it will increase to 5100 km^3 during 2025 with a rise of 8.4 % to 12.2 % from the current rate of withdrawal. In 1995, 76% of the world's population had water availability of less than 5100 m3 per annum per capita, and it is predicted that in 2025, most of the Earth's population will be living under a low water supply. Due to the effects of climate change and uncertain rainfall, water use in agriculture will increase with the expansion of irrigated land. By late 1970, almost all developed and developing countries started intensive irrigation development to ensure increased crop production. Subsequently, the global rate of increase in irrigated areas has slowed down primarily due to the very high construction cost of irrigation systems and soil degradation problems. Thus, many efforts are required to harness the water resource potential and combat the drought and flood in the country. Managing Soil and water resources requires a holistic approach that links socio-economic developmental activities with an eco-friendly environment.

Watershed development projects in India have a long history of development. However, very limited studies were conducted to quantify the impact of watershed interventions on biophysical aspects (Joshi et al., 2008; Glendenning et al., 2012). The effect of IWD interventions on ecosystem services is poorly understood, which has underestimated the impact of watershed management programs in the country. There is also increasing concern about downstream water availability due to watershed interventions in upstream areas, especially in dryland regions (Bouma et al., 2011; Glendenning et al., 2012). The watershed development activities implemented in the rainfed areas have significantly influenced the various biophysical aspects such as Soil and water conservation, soil fertility, positive impacts on cropping pattern, cropping intensity, production and productivity of crops (Barron et al., 2009; Garg et al, 2012). Watershed interventions also help in the increased water table, perenniality of water in wells, water availability for cattle and other domestic uses (Palanisami et al., 2009). However, few studies highlighted the negative impacts on the watershed and catchment scale (Batchelor et al., 2003; Sharma and Thakur, 2007;Bump et al., 2012).

In this scenario, a comprehensive approach to watershed development is necessary to reduce the soil loss, runoff and nutrient loss from various land uses and enhance the water availability in watersheds. Numerous engineering interventions are available to face the above challenges and combat the impacts of climate change on natural resources. The engineering interventions namely Erosion control measures, Gully control structures, Slope stabilization measures, Rainwater harvesting and artificial recharge structures are directly useful to the farmers and other beneficiaries of the watershed.

Erosion control measures

Land degradation due to soil erosion in rainfed areas has a significant effect on onsite (the removal of topsoil) that also causes offsite effects, such as downstream sediment deposition, reduction in storage capacity, nutrient enrichment and water pollution in the downstream water bodies. Hence, many erosion control measures have been undertaken in the watersheds. The first process in soil erosion (from any surface) starts with the detachment of soil particles. Detachment of soil particles takes place with the kinetic energy associated with the falling raindrops. Techniques should be adopted to dissipate this energy to minimize the detachment of soil particles. This can be achieved by intercepting the rain before it reaches the ground surface. Soil movement from one place to another occurs with excess surface runoff. Any means that reduce this excess surface runoff helps reduce soil movement. Flowing water either on the ground surface or in a stream cuts the Soil and erodes it. The process increases with the increase of velocity. Bunding breaks the length of the slope. Terracing breaks the degree of slope. Trenching is more useful with annual crops, horticultural crops, spices and plantation crops.

Gully control structures

Gullies are formed in the soil by the surface runoff water, thereby initiating sheet and rill erosion. Finally, the gullies result in accountable loss of top fertile Soil by erosion. The gully control structures are primarily designed for safe disposal of excess runoff generated from the watershed. Gully control structures like spillways, check dams (loose boulders check dam (LBCD), different size masonry check dams, gabion structure etc) are constructed to stop further advancement of the gully heads and fingers and to improve the moisture regime in the command areas which results in increase in production from agricultural land.

Rainwater harvesting and artificial recharge structures in watersheds

The climate change scenario increases uncertainties in rainfall distribution and the risk of extreme events like floods and drought. These extreme events make rainfed farming more vulnerable. However, suitable water harvesting and artificial recharge structures in a watershed can be the saviour and reduce the dependency on external water sources for agriculture. Fram ponds of various types, percolation ponds and collection wells are a few water harvesting structures commonly adopted in watersheds.

Slope stabilization measures

Slope stabilization and mass erosion control are the major challenges in the hill regions in protecting the land from heavy land degradation, decline in the quality and quantity of water resources, and disruption in the communication lines. Establishment of vegetation in the unstable slopes created due to land slide, mine waste piles, bunds of water resources and road / railway track construction is difficult due to their rickety nature and poor fertility status. Natural fibre based geo-textile (soil cover) have been most popularly used across the globe for erosion control and slope stabilization by establishing vegetation. One of the natural fibre based product in India is Jute geo-textile which is being globally used in various soil conservation applications. Wide choices of jute geo-textiles are being produced and applied in diverse purposes.

Hydrological Impacts of Engineering Interventions in selected Watersheds of Tamil Nadu

River Valley Project in Mettur catchment

To restore the ecological imbalance to prevent environmental degradation and maintain sustainable production in Mettur catchment of Tamil Nadu, various developmental activities were undertaken under RVP on watershed approach in 149 micro watersheds in 2002. The impact assessment study was conducted by evaluating the 22 watersheds randomly selected. The information was collected from 660 respondents. The evaluation team inspected about 25 to 50 per cent of the works for collecting data.

Impacts of soil and water conservation measures

Contour bunding / field bunding and appropriate crop combinations were proposed in the agricultural fields as an in-situ moisture conservation measure. Contour bunds were constructed in the agricultural fields with 5 to 12 % slope. As all field boundaries are not along the contour in fragmented land holdings, filed bunds were constructed. After the construction of bunds few farmers have adopted crop diversification due to enhanced insitu soil moisture conservation. In wastelands and forestlands, contour staggered trenches have been taken up for harvesting runoff water and in-situ moisture conservation in sloping lands. The trees grown in these fields had better establishment and growth due to enhanced moisture content in the soil. The intensive contour and field bunding taken up in the agricultural fields have decreased the runoff and increased the water infiltration. The bunds were strengthened by planting the locally available fodder grasses. It also supports the conversion of the bund area into productive land and the sustainability of these structures. The bunds strengthened with locally available vegetative barriers are considered inexpensive, feasible and durable bioengineering measures.

Impact on Surface Runoff and soil loss

Gauging stations were installed in few selected locations to monitor runoff and soil loss from the watersheds under treatment. Surface runoff was 4.5 to 5.6 per cent of the rainfall for selected rainfall events (Fig 1). Based on silt deposited behind selected check dams/ponds, soil loss was estimated to vary in the 2.3 to 3.51 t $ha^{-1}yr^{-1}$ range, which is very well within the permissible limit.

Impact of artificial recharge structures

Percolation ponds are considered as the important component of RVP watershed intervention for augmenting groundwater recharge in these regions. The storage capacity of

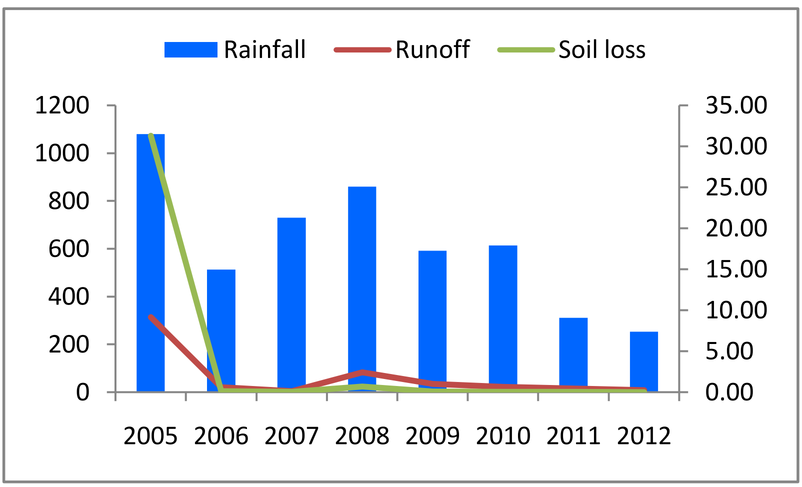

Fig. 1: Rainfall, runoff and soil loss in 4B3B3r2 watershed in Mettur catchment

these PPs varied between 20 ha-cm and 50 ha-cm. The out lets are made by stone pitching with 4-meter length and 2 to 3 m width in parabolic or trapezoidal shape. The additional water storage created helped in average of 5 m raise in water table of the open wells. One or two percolation ponds have filled thrice in a year. The watershed impact data of 187 wells in Mettur watersheds was studied. The data indicates that 50 per cent of the sample wells had water for more than 9 months during the evaluation period as compared to 38 per cent before the project period. The results of recuperation data collected for different watersheds are presented in table 3. Recuperation rate after WSM project increased upto 2.52 per cent in different SWS. The maximum recuperation rate was observed in Bevanatham watershed and there is no change in Karandapalli and Sorankanpudur watershed. The recuperation rate was influenced primarily attributed to distance of wells from the location of water harvesting structure and quantum of water available in the structure besides quantum of rainfall in the watershed. The overall impact in realizing the objectives of the project at Mettur catchments was very good. The project was found to be technically feasible and economically viable. To realize long term impact of the watershed activities and document project sustainability, it is suggested that implementing agency, should monitor the watersheds in terms of socio-economic and bio physical changes in long term period, say at least 10 years after withdrawal of project.

River valley project in South Pennaiyar catchment

The study was conducted in South Pennaiyar catchement in Dharmapuri, Salem, Villupuram, Vellore, Thiruvannamalai districts of Tamil Nadu. The study was conducted for three years period during 2012-14. Sample based before and after project evaluation approach, employing budgeting techniques. A total geological area of 33,652 ha was treated under 101 micro watersheds in south Pennaiyar catchments. Out of the total area, 10,590 ha treated area was covered under 15 watersheds in Dharmapuri, Vellore, Salem and Thiruvannamalai districts for evaluation under this study. The 15 watersheds selected for detailed impact analysis study those represents all the three Districts.

Impact on Surface Runoff and soil loss

Based on data collected by the department in few selected gauging stations located in the treated watersheds it is clearly depicted that the runoff and sediment yield has been reduced drastically. Based on the runoff gauging data available at ponds/check dams, surface runoff was found to be 9 to 12.3 per cent of the rainfall for selected rainfall events. In general, most of the surface runoff was reduced as a result of in situ moisture conservation practices like contour bunds/field bunds, land leveling, etc., in the field and remaining runoff was stored beyond the structures constructed for storing surface runoff with in the watersheds. Soil loss was reduced from 4 to 1.2 tonnes ha^{-1} yr^{-1}due to *in-situ* moisture conservation measures and gully control structures.

In situ soil and water conservation measures

The impact of the contour / field funds was gauged from the increased yield level of various crops ranges from 1.3 to 14.5 per cent. Few of the pockets it was noticed that the crop diversification has been taken place after forming the contour bund. Nearly 10.4 per cent of

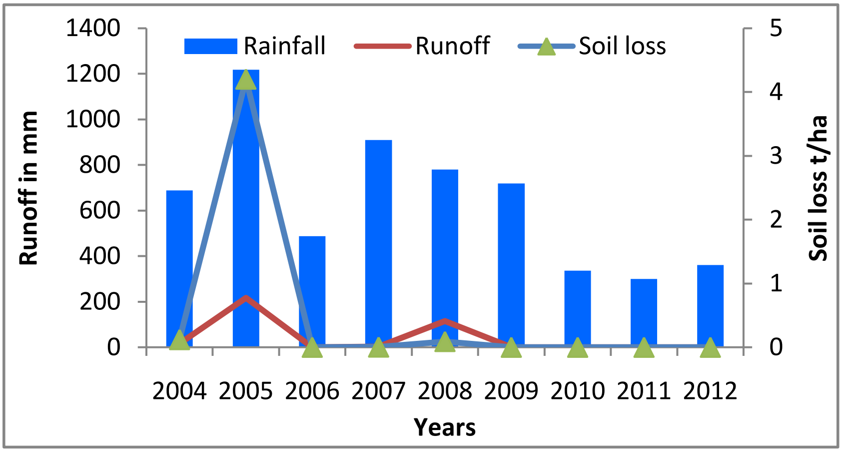

Fig. 2: Impact of watershed interventions on runoff and soil loss in South Pennayar catchment

the amount has been spent for this activity. In low rainfall areas contour bunds can increase sorghum yields by 30–90% with rainfall [28]. The dimensions of trench were 2.50 m length, 0.45 m width and 0.30 m height. Positive impact of the trenches was noticed from the higher growth rate of the plantations / horticultural crops which was found to be satisfactory.

Drainage line treatments

Loose boulders check dams (LBCDs) are mostly constructed in first order streams of upper reaches and found that about 70 per cent of these structures were found to be in good condition and functioning efficiently for the purpose it was constructed. Positive impact was gauged from the quantity of silt accumulated in the upstream side of the LBCDs. Similarly, LBCDs constructed in second order streams of middle reaches are found to be intact at 65 per cent. These structures help in stabilization of stream beds apart from reducing the velocity of water flow. After few years, these LBCDs act as water harvesting structures due to blocking of pores. Due to sediment deposition behind the structures constructed in the streams, the gully bed level is stabilized. The silt deposited behind *ex-situ* conservation measures of sample structures were estimated from SWS is presented in Table 1. Based on silt deposited behind selected check dams/ponds, soil loss was estimated to vary in the range of 1.1 to 1.9 t $ha^{-1}yr^{-1}$, which is very well within the permissible limit. The silt accumulated behind check dams are being effectively utilized by beneficiaries which increase the soil fertility and enhances the growth of vegetation in the nearby region.

Impact on Ground Water Resources

Impact of the interventions such as Water harvesting structures, percolation Pond, Silt Detention tank, contour bunding, etc on ground water was observed to some extent during field survey and discussion with the farmers. Impacts in term of increase in water table duration of water availability in wells with increase in well yield/recuperation under selected

Table 1. Quantity of silt trapped in various structures in South Pennaiyar catchment

Watershed Name	Water Harvesting structures		Farm Pond		Silt Detention Tank	
	No.	Silt deposition (cum)	No.	Silt deposition (cum)	No.	Silt deposition (cum)
Andipatti	1	14.89	1	---	1	15.62
Rungavalasai	2	39.10	2	4.00	2	28.46
Kurumapatti	-	-	-	-	1	8.79
Senrayampatty	3	64.24	2	18.47	8	94.58
Aruvankadu	2	46.21	2	12.34	5	60.12
Veppampatti	-	-	-	-	1	9.58
Elavampadi	1	25.16	-	-	1	6.45
Sattayampatti	3	67.30	4	32.15	7	79.58
Kokkarapatti	4	86.33	4	28.58	7	90.05
Nadur	2	35.17	5	37.29	10	105.42
Periyur	2	24.89	2	21.47	7	65.47
Chinnagummarur	1	48.23	-	-	1	9.16
Beemandapalli	3	52.54	4	19.24	8	95.16
Devaragundhani	2	30.26			9	87.58
Total	**26**	**534.32**	**26**	**173.54**	**68**	**756.02**

watersheds are presented (Table 2). Raise in ground water table observed during the year 2014 in influence zone of water harvesting structures under SWS is presented. It was found that raise in water table varies from 0.10 m to as high as 0.86 m in different watersheds with average rise in water table varies from 0.20 to 0.46 m.

The period to which water remains in the wells for productive purpose is an important aspect as watershed impact data of 162 wells in South Pennaiyar watersheds were studied. Forty seven per cent of the sample wells had water for more than 9 months during the evaluation period as compared to 41 per cent before the project period. The study clearly reveals the watershed management activities under RVP scheme in South Ponniayar had impacted positively in longevity of water availability in wells. The one another very positive aspect of the project was no drying or reduction in water availability in the wells situated at upper location/reaches of the SWS of the study area rather it increases there too. Recuperation rate after RVP project increased in the range of 2.08 to 8.18 per cent in different watersheds. The maximum recuperation rate was observed in Aruvankadu watershed and it was minimum in Bottimadavu watershed. The recuperation rate was influenced primarily attributed to location distance of wells from the location of water harvesting structure and quantum of water available in the structure besides quantum of rainfall in the watershed.

Impact of River valley project in lower Bhavani catchment

The evaluation of 17 sub-watersheds implemented under River Valley Project in lower Bhavani catchments during 1996-2000 on hydrology, bio-physical and socio-economic aspects has been carried out. Participatory evaluation, random sampling technique and

Table 2. Impact of RVP watershed project in recuperation rate in South Pennaiyar

Watershed	Recuperation rate (m^3/hr)			Increase (%)
	Before	After	Increase	
Andipatti	0.82	0.85	0.03	3.50
Aruvankadu	1.10	1.17	0.07	6.53
Beemandapalli	0.96	0.99	0.03	2.86
Bottimaduvu	0.96	0.97	0.01	1.48
Chinnagummarur	1.90	1.95	0.05	2.86
Devaragundhani	1.80	1.88	0.08	4.35
Kokkarapatti	0.70	0.71	0.01	2.08
Nadur	0.70	0.74	0.04	6.18
Periyar	2.09	2.16	0.07	3.33
Rungavalasai	2.09	2.17	0.08	3.90
Sattayampatti	2.00	2.07	0.07	3.62
Senrayampatty	1.80	1.89	0.09	5.26
Veppampatti	2.00	2.07	0.07	3.66

detailed data on different socio-economic aspects were adopted to assess the comprehensive impact of watershed interventions. Appropriate scientific tools and techniques were employed to evaluate the water harvesting structures, silt detention structures and soil conservation structures in the watershed.

Effect on soil loss and runoff

Sample study was conducted to assess the runoff and soil loss from the treated watersheds due to RVP activities. Runoff and soil loss data from Masinagudi silt monitoring station was collected from 2003 to 2005 and the data are presented in Table 3. The annual runoff data shows that there was reducing trend of runoff observed and the quantity of harvested water is in increasing trend from the year 2003. Similarly, the sediment transported from the watershed is in decreasing trend since 2003. The fact was also confirmed with soil loss data collected from the same watershed from the year 1998 to 2005. There was reduction in soil loss from the year 1999 to 2005 at Bj2e watershed which clearly indicates that the soil loss was reduced due to watershed activities in Bj2e watershed. Average runoff reduction was ranges from 4 to 18 % and soil loss reduction was ranging from 4 to 5 Mg ha^{-1} yr^{-1}.

Table 3. Rainfall and runoff from Bj2e watershed in Lower Bhavani catchment

Rainfall (mm)	Runoff (mm)	Percentage of runoff to rainfall	Rain water harvested in the watershed (mm)	Sediment transported from watershed (t/ha)
790.2	349.19	44.19	441.01	1.2
891.3	367.99	41.29	523.31	1.1
744.4	277.78	37.32	466.62	0.4

Water Harvesting structures

Collection wells are being effectively used by farmers for supplemental irrigation of crops with sprinkler irrigation system. The recuperation rate during monsoon and summer season is 0.58 m^3 and 0.31 m^3 respectively. The farmers are pumping water 2 to 3 hours per day for irrigating vegetables like cabbage, potato, carrot, cauliflower, floriculture etc., Some farmers irrigate the tea crop during summer. From a 2 to 3 acre area can be irrigated. The water table has increased in the range of 0.3 to 0.5 m in the influence zone of percolation ponds. Percolation ponds and farm ponds constructed in lower hills were effective in harvesting 4-5 % of runoff from the watershed. Additional storage capacity created during the project period together with the status of actual amount of water harvested and stored during these years is presented in Figure 3. A total of 368 ha-m additional surface water storage capacity has been created. Out of this, 55 % is water harvested through farm ponds followed by 25 % of water harvested by water harvesting structures. In addition to this fixed capacity, storage capacity was repeatedly available for different fillings after the filled water was percolated. The additional water storage capacity has helped in improving ground water recharge and water availability for supplemental irrigation and other non-domestic uses in the watershed.

Positive impact on natural resources in terms of increase in ground water recharge, Silt detention, Increase in-situ moisture conservation, reduction in runoff and soil loss, reduction in silt carrying capacity to reservoirs, Increase in irrigated area and stabilization of gullies was noticed. Production and productivity are also in increasing trend due to RVP activities in the region.

Perspectives of watershed management with engineering structures

- Studies on upstream and downstream linkages at micro and macro regional scales for assessing the impact of watershed management programmes on flow regimes (surface and ground water resources) and the perenniality of streams and rivers must be initiated.

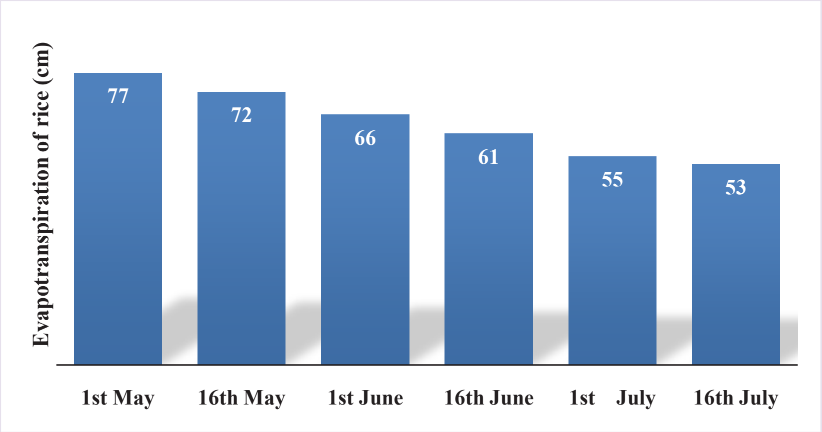

Fig. 3: Additional storage capacity created in lower Bhavani catchment

- Researchers need to concentrate on developing area-specific soil loss tolerance limits and land quality indices for sustainability maintenance.
- Modern scientific tools like GIS and RS can be used to assess the impact of various interventions in the watershed. These tools also help identify sites for proposed engineering structures.
- Geo-tagging of the structures in the watershed and the proposed structures should be mandatory for monitoring the periodic changes in hydrology, water resources, vegetation, etc., before and after implementing the engineering structures at the watershed.

Conclusion

The overall impact on runoff, soill loss and enhancing water availability was in increasing trend in all the watersheds. The impact over the period is also in incaresing trend and larger impact was observed after 10 years of implementation of the project. Annual surface runoff reduction based on the recorded data in selected watersheds was 4.0 to 6.0 per cent of the rainfall for all watersheds. There was reduction in soil loss over the period of five years which clearly indicates that the soil loss was reduced due to watershed activities ranges from 4 to 5 t ha^{-1} yr^{-1}. It was found that raise in water table varies from 0.10 m to as high as 0.86 m in different watersheds with average rise in water table varies from 0.20 to 0.46 m. About 50 -55 % water harvested through farm ponds followed by 25 % of water harvested by water harvesting structures and indicates that micro scale water harvesting structures are efficient to store the surface water and recycling. Hence, the study recommends to continue the impleemnation of engineering interventions in larger scale to enhance the water availability and reduction of soil erosion which will mitigate the climate change impact.

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Evaluating the water resource management in an agricultural sector under climate change using a Risk-Based Hydro-Economic Model

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Introduction

As an essential environmental challenge in the 21st century, climate change is crucial because it affects many aspects of our lives, livelihoods, health, future, and even financial markets and insurance systems (Kemfert, 2009). Furthermore, agricultural activities and yield were depended on climate compared to other sectors. Cattivelli et al. (2008) reported that production would be limited to more than half of arable land in the next 50 years with continued global warming. FAO (2012) also dedicated that climate changes can harm safety because agriculture would be considered an economic activity for supplying food and guaranteeing perpetual food safety. For instance, Ajichay basin in northwestern Iran around the Urmia Lake has lost its efficiency under climate change and some anthropogenic activities i.e., overuse of groundwater, inappropriate cultivation patterns, and the expansion of economic sectors. Therefore, water resource management is necessary at this basin.

The field observations revealed that irrigated agriculture is approximately 23%, 38%, 12%, 8%, 7%, 7%, 3%, and 2% in Tabriz, Sarab, Bostan Abad, Heris, Azarshahr, Osku, and Shebestar covering Ajichay basin, respectively. Among the aforementioned areas, Tabriz and Sarab were considered the main production areas. Moreover, Sarab plays important role in horticultural and agronomy products and, thus, more water consumption. Consequently, water consuming management in Sarab County is suggested to remediate both quality and quantity of water in Ajichay basin. Management scenarios are: I) low irrigation of agricultural products; II) reducing the share of agricultural water; III) increasing the efficiency of irrigation; and IV) shifting cropping patterns to products with lower water consumption. Finally, some procedures i.e., hydro-economic model is appropriate for policymakers to evaluate water resources (Blanco- Gutiérrez, 2013). It is also a suitable method for assessing the effects of climate change on water and agriculture (Groves et al., 2010; Zhang et al., 2017).

The afore mentioned studies focused on the water supply in addition to its management. hydro-economic models assist to retrospective monitoring as well. Medellan-Azuara et al. (2010) studied a vast domain of options for managing the water systems in North California and Mexico through a hydro-economic model. After that Kahil et al. (2015) applied the hydro-economic model to study the management policies of efficient water and necessary adaptations with changes in the climate in the Jucar River basin. Using the hydro-economic model, Varela-Ortega et al. (2016) investigated the effects of climate change around the Guadiana River basin. Overall, they found that a severe climate change decreases available water and crop yield. It was also found that changing on cropping pattern may decline water requirement. Rafiei Darani et al. (2017) applied the WEAP model in Neishaboor plain to influence economic output planning. Obviously, converting cropping patterns followed by modification in marketing networks increases water consumption and subsequently declines the water table level in Neishaboor plain. The effects of climate change and social-economic scenarios on the present and future water Climate change impacts were also simulated for upstream Indus River during 2006 to 2050 using the WEAP model (Amin et al., 2018). Other studies have also benefitted by different hydrologic models i.e., MIKE BASIN, MODSIM, SWAT, and WaSIM. There are a few studies which have applied WEAP along with social-economic models. For instance, Purkey et al. (2008) combined WEAP and econometric models to estimate the effects of climate change on agricultural water. Furthermore, Varela-Ortega et al. (2011) utilized WEAP and an optimized economic model to evaluate groundwaters' climate uncertainty.

MATERIAL AND METHOD

Location of research and initial works

This research was performed in Ajichay basin with an area of about 12600 km^2 in the north-west of Iran (East Azerbaijan Province) and eastern part of Urmia Lake. It is the biggest sub-basin of the Urmia Lake after the Zarrinerood. (Fig. 1). To include the variations in farmers' habits, water resources, and fertility of lands, the Ajichay basin was divided into 36 plains through Google Earth. The rivers direction was then identified to monitor the output for upstream and downstream sub-basins throughout the process of extracting sub-basins using GIS. Therefore, mountain and plain areas were separated for all rivers and their branches to the greatest extent possible.

One benefit from this process is separating the hydrologic modeling of mountainous areas from plains and the agricultural regions (slope areas) and estimating their variables separately. It increases the modeling accuracy. The next benefit is finding an opportunity to determine input flow to each plain and agricultural area through modeling.

The hydro-economic model

Since hydro-economic models comprise integrating hydrologic and economic elements, the main framework of the present study is to have a pattern patterned based on these two elements. Both economic (Mathematical Programming Method, MPM) and hydrologic (WEAP-MABIA) models were performed separately, while the output of one model was used as an input for the other model.

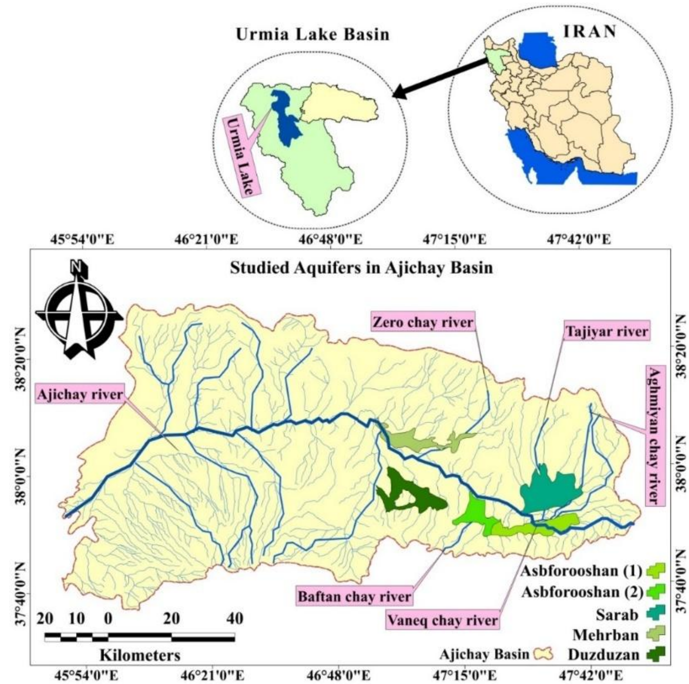

Fig. 1: An Overview of the Ajichay Sub-basin

The economic model

Mathematical Programming Method is an optimization model that shows farmers' behaviors in risky situations through a risk-based quadratic risk programming (QRP) method. This model determines the optimal amount of land for allocating to different products. This model aims to maximize the expected farmers' utility to some technical and structural restrictions. It is widely used to analyze managing agricultural resources and decision-making about cropping patterns (Varela-Ortega et al., 2011; Blanco-Gutiérrez et al., 2013; Esteve et al., 2015). Buysse et al. (2007) showed that it is an appropriate model for analysing issues related to agriculture and natural resources. The objective function (Eq. 1) shows the maximum expected utility of farmers, which is calculated by subtracting the risk element from the net income (Z) for each crop (Hazell and Norton, 1986). This model includes the farmers' goals and limitations and involves the number of beliefs about the risk perceptions and risk attitudes. The risk element is a combination of farmers' risk-aversion coefficient (φ) and the standard deviation of income distribution ($\sigma(Z)$) caused by a set of natural, climatic, and marketing variables. To separate parameters from variables, the latter and the former are respectively presented in capital and small letters:

$$\text{Max } U = Z - \varphi.\sigma(Z) \qquad \text{... (1)}$$

The risk-aversion coefficient of farmers shows their risk attitude while selecting between profiting and risk aversion. Risk-neutral farmers ($\varphi = 0$) try to maximize their profits and cultivate profitable and high-risk crops. Risk-averse farmers ($\varphi > 0$) reject any risk, try cultivating crops with low risk, and sacrifice part of their profit to risk. Several theoretical studies in the past eras (Friedman and Savage, 1948) and many experimental studies (Chavas, 2004) have shown that most farmers prefer risk aversion and try maximizing the utility instead of maximizing the profit. The farm income is calculated by Eq.2, where $gm_{c,r}$ is the gross profit per crop *(j)* and technique (*r*), which comes from the difference between incomes (cost multiplied by yield) and production costs. $X_{c,r}$ is the area under cultivation, *fco* is the family's opportunity cost, $hlab_p$ is the number of family's labor, *hlw* is hired labor wage, $hlab_p$ is the number of hired labor, wpm^3 is the volumetric price of water, *WC* is the amount of water used in the farm, *wpha* is the irrigation water fee paid per hectare, and *sirrg* is the irrigated area in the farm (Esteve et al., 2015).

$$Z = \sum_c \sum_r gm_{c,r}.X_{c,r} - fco.\sum_p flab_p - hlw.\sum_p hlab_p - wpm^3.WC - wpha.sirrg \qquad \text{... (2)}$$

The above maximizing function has some constraints, such as water limitation (the most affecting factor due to climate change), which are presented in Eqs. 3-8:

$$\sum_{j=1}^{J} \frac{w_{jsr}}{eff_r} x_{js} \le W_s \qquad \forall s \qquad \text{.. (3)}$$

$$\sum_{j=1}^{J} l_{js} x_{js} \le L_s \qquad \forall s \qquad \text{... (4)}$$

$$\sum_{j=1}^{J} m_{js} x_{js} \le M_s \qquad \forall s \qquad \text{... (5)}$$

$$\sum_{j=1}^{J} f_{tjs} x_{js} \le F_{ts} \qquad \forall t, s \qquad \text{...(6)}$$

$$\sum_{j=1}^{J} pe_{zjs} x_{js} \le PE_{zs} \qquad \forall z, s \qquad \text{... (7)}$$

$$\sum_{j=1}^{J} \sum_{s=1}^{S} Sch_{js} x_{js} \le A \qquad \text{... (8)}$$

Equation 3 indicates water use restrictions. In this constraint, W_{jsr} is the water required during the season *s*. Additionally, eff_r is the irrigation efficiency in per region *(r)*, and W_s is the total available water (m^3) during season *s*. Equation 4 also shows the number of hired labor (1_{js}) for one-hectare cultivation of crop *j* in season *s*, and *Ls* shows the total available labor during season *s*. Inequality 5 is related to the periods of using agricultural machinery, in which m_{js} shows the hours of machineries in one hectare of crop j in season s, and M_S shows the total available hours of agricultural machinery during season *s*. Inequalities (6) and (7) are about fertilizers and pesticides, respectively. F_{ts} shows total available fertilizer of type (*t*) during season *s*, and PE_{zs} is applied for total available pesticide of per type of it *(z)* during *s*. Finally, equation 8 is about land in which *A* shows total farmland area and Sch_j denotes cropping area per crop (j) in season *s*. Farmers' risk aversion is used for model calibration. The accuracy of the calibrated model was estimated by the percentage of absolute deviation (PAD) calculated through Equation (9).

$$PAD = \frac{\sum_{c-n}^{n} \left| \overline{X}_c - X_c \right|}{\sum_{c-n}^{n} \overline{X}_c} \times 100 \qquad \text{... (9)}$$

where, $\overline{X}_c$ is the observed (%) and stimulated (%) amount. The proper calibration happens when PAD approaches zero. Model validation is done using statistical parameters for comparing the simulated and observed land and labor.

The hydrologic model

Various models estimate the water condition in the basin level in the hydrologic section. For a better model selection, available data and facilities, model structure, and its connection to other sections should be considered. WEAP is an appropriate model in hydro-economic modeling due to its availability and capability among the economic models. In this research, we applied MABIA in WEAP to simulate daily evapotranspiration and estimate crops' yield and water requirements (Allen, 1998). MABIA uses a two-part crop coefficient (Kc) described in FAO-56, in which K_c is divided into two crop coefficient base (Kcb) and a secondary factor, called evaporation coefficient (Ke), which shows the evaporation from soil surface. When the surface of soil is dry, but there is considerable moisture in the root area that can compensate for the evaporation of the crop, the base crop coefficient shows a real ET situation (Sieber and Purkey, 2011). MABIA generates daily data while WEAP generates data on a monthly basis. Thus, daily data generated by MABIA were calculated for monthly usage of WEAP.

The hydrologic model (WEAP-MABIA) was calibrated based on parameters i.e., soil water capacity, deep water capacity, runoff resistance factor, rootzone conductivity, deep conductivity, and preferred flow direction. The validity of the model was also evaluated after calibration for making correct predictions. Assuming the fixed variables and calibrated parameters are constant, the model's outcomes are compared to observed data from other periods. Calibration is conducted manually through statistical parameters to compare observed and simulated models. The accuracy was also assessed using Nash Sutcliffe coefficient (NASH) (Eq. 10) and error of bias (Blanco- Gutiérrez et al., 2013) (Eq. 11) values.

$$NASH = 1 - \frac{\sum_{i=1}^{n} (Q_{s,i} - Q_{o,i})^2}{\sum_{i=1}^{n} (Q_{o,i} - \overline{Q}_o)^2} \qquad \text{... (10)}$$

$$BIAS = 100 \times \frac{\overline{Q}_s - \overline{Q}_o}{\overline{Q}_o} \qquad \text{... (11)}$$

where, $\overline{Q}_s$ and $\overline{Q}_o$ are simulation and estimated values, respectively. Also, $Q_{s,i}$ and $Q_{o,i}$ are simulation and observed values according to i as the time and n as the number of observations. Calibration is considered appropriate when BIAS approaches zero and Nash moves toward 1.

Model integration

The hydrologic and economic models run independently; however, the output of one model was used as an input for the other (Mainuddin et al., 2007; Maneta et al., 2009). Increasing irrigation efficiency through implementing a change in irrigation systems from surface to accelerated one was decided as a scenario for managing water resources. It is assumed that j crop in i location is irrigated by surface irrigation method. Considering the amount of evapotranspiration during irrigation seasons as $ET_{actj,}$ and the whole irrigation efficiency as $EF_{irrsurfj}$, the irrigation water consumption of the crop ($V_{irrsurfj}$) is calculated as:

$$V_{irrsurfj} = \frac{ET_{act\ j}}{EF_{irrsurf\ j}} \quad \text{... (12)}$$

According to the main objective of this research, which is to reduce water consumption in agriculture, it was assumed that the amount of the actual evapotranspiration of crops in the suggested management scenarios is equal to actual evapotranspiration of crops in the current condition. The irrigation efficiency of the crop will be increased from $EF_{irrsurfj}$ to $EF_{irrprzj}$ by changing the irrigation system from surface to pressurized system. Thus, the water consumption of j for the crop is calculated through:

$$V_{irrprzj} = \frac{ET_{actj}}{EF_{irrprzj}} \quad \text{... (13)}$$

$V_{irrprzj}$ is the amount of water consumption of j for the crop in pressurized irrigation scenario, and $EF_{irrprzj}$ is the efficiency of whole irrigation during pressurized irrigation. Thus, the amount and percentage of reduction in water consumption for producing crop j in a scenario of an improvement irrigation system from surface to pressure are equal to:

$$\Delta V_{irrprzj} = \frac{ET_{actj}}{EF_{irrsurfj}} - \frac{ET_{actj}}{EF_{irrprzj}} \quad \text{... (14)}$$

$$PV_{irrprzj} = \frac{\dfrac{ET_{actj}}{EF_{irrprzj}} - \dfrac{ET_{actj}}{EF_{irrsurfj}}}{\dfrac{ET_{actj}}{EF_{irrsurfj}}} \times 100 = \frac{(EF_{irrsurfj} - EF_{irrprzj})}{EF_{irrprzj}} \times 100 \quad \text{... (15)}$$

$\Delta V_{irrprzj}$ is the amount of reduction in water consumption for j as a crop due to the substitution of surface irrigation with pressurized irrigation ($EF_{irrprzj}$). The $PV_{irrprzj}$ variable shows the percentage of reduction.

Results and Discussion

Climate change scenarios were simulated using the LARS-WG model with three emission scenarios of A2, B1, and A1B for the period from 2018 to 2050. Overall, the results showed that the average rainfall would be declined by above-mentioned three scenarios, while the average annual temperature will be increased. Rainfed wheat is the largest cultivation area, on contrary, bean is the smallest one across the study area. Variation on the cultivation area by each crop due to climate change showed that the highest change belongs to A1 scenario. Figure 2 illustrates the cultivation patterns caused by climate change. It indicates that farmers reduced water demand, tried changing the cropping patterns to wheat and barley, and limited the cultivation of alfalfa, bean, and potato by the climate change scenario compared to the baseline scenario.

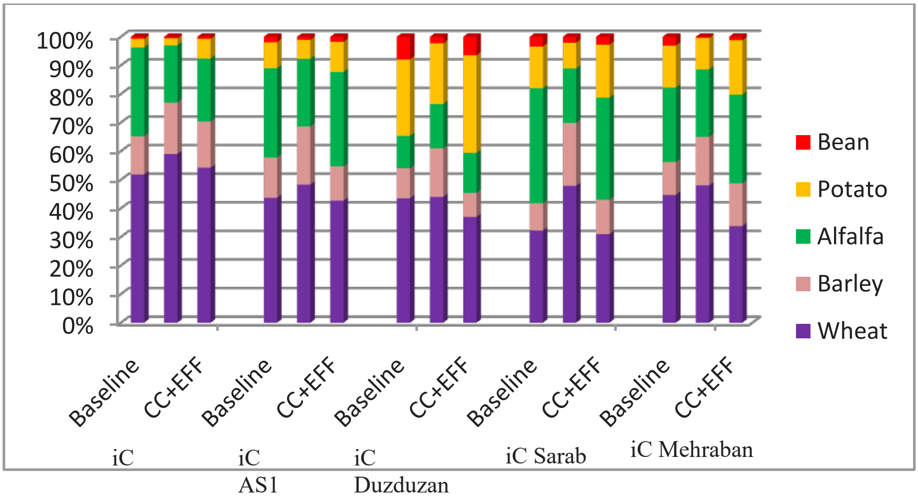

Figure 2. The percentage of variations in cultivation patterns following the climate change scenario

The cropping pattern by climate change scenario has moved toward crops with less water consumption. However, the simultaneous implementation of the climate change and agricultural water reduction scenarios has caused a decrease in the cultivation of crops with more water consumption. Although potato requires more water requirement than beans and alfalfa, it had a low reduction in area under cultivation due to high profits for farmers. In general, the cropping pattern is moving toward crops with less water requirement and more profits (Fig. 3).

It is essential to study labor employment to predict the risk of losing jobs among farmers in case of severe climate change and reduced agricultural water without considering substitute work opportunities. Sarab has the greatest number of labors in the agricultural sector compared to the others. Also, Sarab's share of agricultural work employment is 3.9 times more than the average in the other parts of the basin. Generally, it can be concluded that agriculture

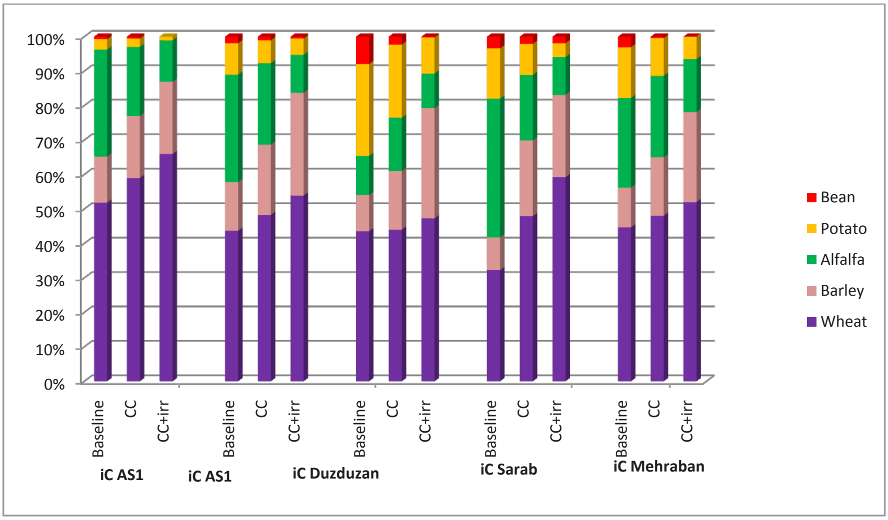

Figure 3. The percentage of variation in cropping patterns following agricultural water reduction scenario

in Sarab city is more dependent on the Ajichay basin. Implementing the A2 scenario results in a 14.48% decrease in the area's average agricultural employment. The agricultural water reduction scenario alone results in a 5.9% decrease in labor, whereas the increasing irrigation efficiency scenario has an 8.9% decrease in water use. Applying the agricultural water reduction scenario along with climate change reduces employment by 17.2% in the region by reducing the area under cultivation of crops that require a lot of labor. Overall, the current study's findings revealed that without changing the management strategies, there would be a considerable reduction in crop yields.

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Revival of Ponds for Enhancing Water Resilience: A Policy Implication

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Introduction

In "Amrit Sarovar" and "Jal Shakti Abhiyan" of Government programme, emphasis has been given on revival of degraded and defunct ponds in order to enhance the productivity and resilience in India's water stressed condition. The available per capita water supply in India is anticipated to decline, decreasing from 1545 cubic meters in 2011 to 1341 cubic meters by 2025 and further to 1140 cubic meters by 2050.Mewat district of Haryana, inhabited by mostly *Meo*communityis largely rainfed and frequently encounters water stress. NCT of Delhi is also facing water stress, waterlogging and groundwater depletion. The situation worsens due to non-operational or poorly functioning water bodies, wetlands, and reservoirs. To address these combined issues, a practical solution involves effectively utilizing surface water resources by implementing extensive water harvesting systems. These should be combined thoughtfully with the use of groundwater reserves. Climate change, population growth, and rapid urbanization pose a huge future challenge to water management, and, to ensure the ongoing reliability, resilience and sustainability of water resources, a paradigm shift is required. Traditional water bodies *Johad, pokhar, talab*, tank, etc. are the main water source for agricultural and other uses. These water harvesting structures (WHSs) hold the potential to meet the growing water demand as well as the solution to the above problems.Therefore, here status of waterbodies/ponds in Nuh watershed of Mewat and NCT of Delhi were explored, then the scientific protocol was developed for revival of pond and optimal plan developed for its climate resilient sustainable solutions.

Materials and Methods

The study was carried out in Mewat and Nuh watershed of Haryana as well as NCT of Delhi, India. The evaluation of existing waterbodiesin Nuh block and Nuh watershed w.r.t. their functionality, quantity and quality, therefore, spatio-temporal evaluation of storage capacity of WHSs and quality of stored water were studied for the study areas using Remote sensing, ArcGIS and primary survey. Existing locations were identified using google earth pro and groundtruthing. Similarly, for NCT of Delhi, for identification of water bodies hybrid mode of supervised classification and NDWI methods were employed using Google Earth Pro. Before that all thematic maps of elevation, slope, contour maps etc. were developed in ArcGIS environment and downloaded DEM. Sentinel 2A was used for preparation of land use and land cover map. FAO gridded data were used for getting daily long-term rainfall data and isohyets were prepared using ArcGIS through IDW technique. Daily runoff was estimated using NRCS-CN methods after getting hydrologic soil group and then finding the weighted curve number for whole NCT of Delhi as well as individual water bodies after delineation of watershed areas in GIS environment. After location of existing waterbodies, spatiotemporal changes in in storage area studied. Out of the existing waterbodies, one waterbody was selected and detail water budgeting was done using standard procedures. Optimal crop planning was developed using Linear programming either by increasing cultivated area or improving production per unit area through efficient use of available resources by considering water availability and other resources to make it climate resilient.

Results and Discussion

It was found existence of 183 village ponds and 20 earthen dams in Nuh block, out of these 80 village ponds and all earthen dams were surveyed. The main problem in earthen dam constructed were damage of bunds/spillways and no core walls; whereas in village ponds, siltation, no hygiene, non-maintenance and improper location.75% of WHSs are about 30-50 years old, gradual decrease in storage capacity (4-30%) and in bad conditions during last two decades. Water quality analysis for pre-monsoon, monsoon and post-monsoon season of stored water fed by rainfall/runoff, canal and sewerage water showed that WHSs close to villages were used as disposal sites of toilet water creating nuiscence. WHSs fed with canal and sewerage showed substantially higher BOD. Irrgation Water Quality Index developed showed that out of the 80 WHSs, 75 WHSs fell under medium category of suitability during pre-monsoon and 78 WHSs each during monsoon and post-monsoon period. Overall, the majority of the WHSs in Nuh block are moderately suitable for irrigation.

In Nuh watershed the surface runoff from the watershed was 18% annually and 16% during the monsoon season over the period from 1999 to 2020. The classification highlights the scarcity of water harvesting structures in the hilly region with high runoff generation, while the plain region experiences moderate to low runoff, indicating a lack of surface water resources. These findings significantly enhance our understanding of the watershed's hydrological dynamics, emphasizing the overall low distribution of runoff.335 pond structures were identified as existing water harvesting structures in the Nuh watershed. Ground truthing was conducted to validate these findings on-site. In Nuh, a total of 287 water harvesting structures ponds were identified, while in Gurgaon, 48 water harvesting structures were identified.In NCT of Delhi 488 waterbodies were found out of which 21 dries up during non-monsoon season and most of the waterbodies in bad shape and deteriorated. Water bodies occupied 2092.12 ha area which is 1.40% of NCT of Delhi. and witnessed an annual surface runoff ranging from 58mm to 621.36mm (Figure 1). The total water availability in water bodies is 10.89 Mm^3.

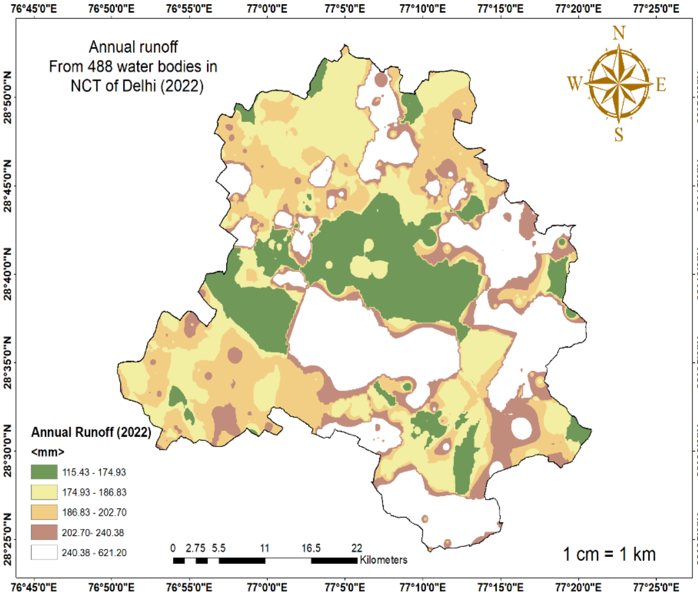

Fig. 1: Spatial variability of surface runoff in NCT of Delhi

Fore revival of waterbodies, one pond in Untka village was selected and rejuvenated following scientific protocol. Participatory and scientific design was done for the pond selected in Unka village with deepening upto 1.5 to 2 m, two bath ghats, retaining walls, grass turfing/sodding, and stone pitching with proper shoulder bunds and berms. Collaboration was made with Additional Deputy Commissioner (ADC) and the Block Development Officer (BDO) of the Nuh District, MNREGA personnel and Sehgal Foundation and interactive sessions with the farmers were held on the importance of the village ponds and their revival need. Due to revival of pond an additional storage volume of 22800 m^3 was created. The total command area found to be 31.18 haand there was increase in the command area by 2.15 times with the existing cropping system. To utilize this stored water optimization plan was being developed using LINGO software. The stage and storage relationship shows R^2 equals to 0.9663 suggests that there is a strong relationship between the stage and the storage in a water bodies. The net return from each crop were calculated by deducting cost of cultivation from gross returns from main products and by products of respective crops. The annual net returns from existing cropping patterns under rainfed condition are Rs. 62,405 per ha per year, which increase to Rs. 86,676 per ha per year with the LP model under surface irrigation conditions. Different scenarios developed under surface drip and pipe irrigation show net returns of Rs. 3,93,281, Rs. 4,11,176, and Rs. 4,29,071 per ha per year, under 60:10:40, 50:10:40 and 40:20:40 scenario respectively. The LP model yields 18% and 49% higher net returns in under first scenarios 60:10:40 compared to the surface irrigation condition. The best scenario with a ratio of 50:10:40 results in Rs. 4,11,176 per ha per year under minimum water requirement 14.03 ha-m of water.

Conclusion

For sustainable development precise information of various sector are required as demand of agricultural sector and domestic are increasing day by day. So, the status of waterbodies and the storage volume is essential and their revival. Using modern tools like google engine, ArcGIS and google earth pro helps in getting more information in short time. So, this study can conclude to use advance tools for better and quick study of water demand. Since water demand is more than water availability for water bodies therefore, these water bodies can be revived through Amrit Sarovar and Jal shakti Abhiyan programme of Government of India, and also for reducing the siltation to the water bodies proper catchment treatment should be done on a bottom-up approach. With efficient water management practices and improved crop management practices this water demand can be fulfilled and also the flooding and drought situations can be managed and making it a climate resilient. In these studies, the analysis and evaluation to support the development of reliable, resilient, and sustainable solutions with bottom-up, convergence and linkages with participatory approach may be used to make it successful. A restored, and well-managed ponds directly or indirectly contribute to (a) regenerating natural capital (i.e., biodiversity, water cycle, nutrient cycle, and water quality); (b) keep resources in use (i.e., enhance resource use efficiency of material and energy); and (c) design out waste externalities (i.e., reduce environmental impacts, waste reduction, and economic sustainability). Further suitable management strategies for avoiding direct inflow of village sewerage and canal water to waterbodies by installing suitable eco-friendly water treatment plant, desilting of ponds alongwith scientific design and integrated farming system can be adopted for improving water quality alongwith enhanced irrigation potential and income of stakeholders. This detail procedure explained will be guideline for policy makers and other Government and private officials who are engaged in sustainable water resource management to make it resilient.

Precision N management using sub-surface drip fertigation in maize-wheat system

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Introduction

Global food and nutritional security are the key challenges before the world, further toughened by rise in global population and climate changes. Food shortages are reported from many developing countries. As many as 828 million people (about 10% of world population) suffer from hunger. This scenario points to the need for efforts towards increasing agricultural production. Water and nutrient supplies are the key drivers of agricultural production thereby influences food and nutritional security. Among various agricultural inputs, fertilizers contribute about 30–50% towards yield performance (Stewart, 2002; Dass et al., 2015b; Joshi et al., 2018). Despite all research and development breakthroughs in agriculture, the water and nutrient-use efficiencies are still low at farm level. Concerning nutrients, their use efficiency can be assessed using different indices. Agronomic efficiency (AE) is one of the indices, calculated as the increase in yield per unit of nutrient applied, which is easy and often used. Among all nutrients needed by plants, N has the largest contribution towards the crop yield enhancements. Thus, monitoring and maintaining high NUE assumes great importance in India because it is the second-largest consumer of fertilizer N in the world. For N-application to cereals, typical AE values range from 10 – 30 kg grain kg−1 N fertilizer applied. The AE is the mathematical product of two other NUE concepts: recovery efficiency (RE) and physiological efficiency (PE). The RE is the proportion of the nutrient applied as fertilizer that is taken up by the plant and is influenced by fertilizer management and crop nutrient needs. For N fertilizer, typical values for RE are in the range of 0.30–0.50 kg kg−1. The PE describes the ability of plants to transform acquired nutrients into economic yield and is impacted by partitioning, environment, and management. For N fertilizer applications to

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cereals, typical PE values range from 30 – 60 kg yield kg−1 N taken up by the plant (Sylvie *et al*., **2023)**.Thus about 40–70% of applied nutrients are either lost or leached down beyond the root zone and remain unutilized by the crops grown. Further, Singh (2023) reported that **t**he proportion of fertilizer N in the total N input for crop production in India is increasing since the advent of the Green Revolution in the mid-1960s, but NUE has declined from 48 to 35% in 2018; NUE in North America was 58% in 1961 and 53% in 2018 (Singh, 2023).Low N-use efficiency results in yields lower than the achievable**.** Besides this, environmental pollution and global warming are the other serious issues related to existing nutrient management practices (Dass *et al.,* 2014 b), especially so for N management with a low recovery efficiency. Greenhouse gasses emissions (N_2O, N_2 etc.) are associated with improper application of N. Moreover,N leaching losses increased and use efficiency decreased when fertilizer application rates exceeded crop N requirements (Van Es *et al*., 2020) apart from environmental pollution.

Decreasing irrigation water availability is another strong hindrance to the sustainability of agriculture. According to a study by the National Geophysical Research Institute, the largest depletion of groundwater in the world is happening in north India, with Delhi as the epicenter; water scarcity can lead to loss of up to 6% of GDP by 2030 (Aggarwal, 2019). Ground water is the major contributor to irrigation, contributes 60% of total irrigation (Abhilash *et al*., 2020) but it being pumped out 70% faster than was earlier estimated (Aggarwal, 2019); the overdrafting of groundwater has led to water crisis in many states of the country which is a serious concern. Almost 89% of the groundwater extracted is used for irrigation and the rest for domestic (9%) and industrial (2%)use (https://www.civilsdaily.com/Burning Issue-Groundwater-Depletion-in-India/) and about 54% India faces high to extremely high water stress. Agriculture sector that consumes more than 80% of India's water resources has a very low overall average water-use efficiency, about 38% (TERI, 2018)**.**Conserving water in agriculture can have tremendous impact on industry and beyond. However, even with best crop management practices, WUE in surface methods of irrigation, which are widely practiced in India,seldom exceeds 60%.

One of the principal causes of low water and nutrient-use efficiency is conventional methods of application, like surface methods of irrigation and broadcast method of fertilizer application where precision in application of both of these resources is often gets overlooked. However, fertigation employing micro-irrigation including sprinkler and drip irrigation systems have been shown to improve both nutrient-use efficiency and WUE. While fertigation using sprinkler irrigation may have some negative effects on crops, surface-drip irrigation has merits in terms of higher productivity, profitability and resource-use efficiency. Drip irrigation has been promoted for adoption manly in crops like maize, sugarcane, wheat, vegetables. However, adoption drip irrigation and especially drip fertigation has been low in field crops due to their field applications (surface drip) issues with conventional tillage based management systems wherein drip laterals has to be removed and placed at multiple times due to several operations during the growing season.On the other hand, in subsurface drip fertigation (SSDF) system laterals with drippers are established 15 to 30 cm below the ground,depending upon soil conditions and nature of crop, and there is no necessity of anchoring laterals during the crop-growing season and thus economic life of laterals gets prolonged. Moreover, the SSDF system allows for delivery of water and nutrients directly into the root zone as and when needed, which enables the plant fast absorb water, and nutrients as per requirement and almost omitting the deep percolation and evaporation losses of water, and leaching and volatilization losses of applied nutrients. These attributes of SSDF leads to efficient water and fertilizer application; weeds growth is minimized and labour cost is reduced. Also, dripper laden lateral being installed sufficiently below the groundmechanized cultural practices including tilling, sowing, weeding, harvesting, etc., can be performed easily in SSDF compared to SDF. Overall, sub-surface drip fertigation can address the issues of both nutrient and water productivity both in conventional till and conservation agriculture based production systems. Thus, National Agricultural Science Funded (NASF) sponsored field experiments were conducted in the research farm of Division of Agronomy, ICAR-Indian Agricultural Research, New Delhi to study the effect of sub-surface drip fertigation on yield and water productivity of maize and wheat grown in sequence.

Materials and Methods

The field experiment was established at the research farm of Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi (28°38'23" N, 77°09'27"E and 228.6 m above MSL of Arabian sea) during *kharif* on a sandy loam soil. The study site i.e., Delhi, the Union territory and national capital of India, has sub-tropical and semiarid type climate with hot and dry summer and cold winter. Delhi falls under the agroclimatic zone "Trans-Gangetic Plains". Summer months, May and June are the hottest with maximum temperature ranging between 41 and 45°C, although temperature decreases from September onwards. January is the coldest month of the year with a minimum temperature ranging from 5 to 7°C. The mean annual normal rainfall is 1126.3 mm; July and August are the wettest months. The summer season is intercepted by the south-west monsoons. The annual mean pan evaporation is about 850 mm. The relative humidity attains the maximum value (70–77% or even more) during south-west monsoon period and the minimum of 30– 45% during summer months.

The soil of experimental field is sandy loam in texture, neutral in soil reaction, low medium in organic carbon, phosphorus, lowin nitrogen and high is potassium. To carryout the study, the SSDF was installed in 2021 in 2.5 acre area (1.5 acre area in Agronomy Field under conventional cultivation, and 1 acre in Soil Science Division Field under conservation Agriculture). The laterals were established at 20 cm depth below the ground 45 cm apart. The lateral have inline drippers fixed at 30 cm interval. The current study was carried out using Part of SSDF installed in MB 3A field of Agronomy Division. There were nine treatments, No-N (control); 50% RDN with 3-splits; 50% RDN with 4-splits; 75% RDN with 3-splits; 75% RDN with 4-splits (1/4 at 20 DAS + 1/4 at 35 DAS + 1/4 at 50 DAS + 1/4 at 65 DA; 100% RDN with 3-splits; 100% RDN with 4-splits; 50% RDN + 2 Nano-urea sprays and surface irrigation with RDN (conventional system). Each plot had 13 laterals with length 40 m each. All nutrients like including N as per treatments, common amount of P and K across the treatments were applied through drip fertigation only in two equal splits, basal and 25 DAS. Recommended dose of fertilizers comprised 150-60-40 kg/ha N-P-K . The P and K will be given in 2 equal splits (basal and 25 DAS). Crop varieties used in the study include HQPM 1 (double bio-fortified) for maize and HD 2967 for wheat.

Plate 1: Sub-surface drip fertigation system installed in MB 3A plot of Agronomy Division, ICAR- IARI, New Delhi

Results and Discussion

In maize, using 50% RDN through sub-surface drip fertigation yielded at par grain as with 100% RDN applied through conventional methods. Fertigating 75% RDN remained similar to 100% RDN under SSDF, for yields thus, fertigation using SSDF results in 25-50% N saving over conventional RDN application (Fig. 1). Stover yield was significantly higher with 100% RDN (fertigated) over 50% RDN. Stover yield was alike between 100%RDN applied conventionally (basal dose soil incorporated and top dressing) and 75%RDN fertigated.

In wheat, SSDF of 100% RDN in wheat increased yield by 10% over 100% RDN applied with conventional method. SSDF of 75% (4 splits) improved grain yield by 7.5%. Wheat grain yield with 50% RDN (SSDF) was comparable with 100% RDN (conve.), indicating 50% reduction is N dose (Table 1). Within SSDF treatments, 100% N applied either in 3 or 4 splits stood at par with 75% N in either of the two splits applications. Moreover, 50% N fertigated

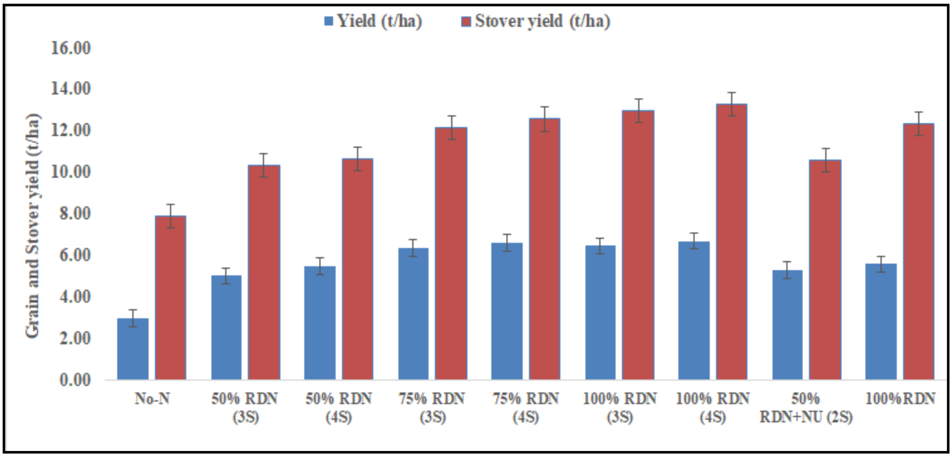

Fig. 1: Effect of sub-surface drip fertigation of N on maize grain and stoveryields

Table 1. Effect of sub-surface drip fertigation of N on wheat on yield and harvest index of wheat

Treatments	Grain yield (t/ha)	Straw yield (t/ha)	HI (%)
No-N	3.39	6.18	35.4
50% RDN (3S)	5.30	7.91	40.1
50% RDN (4S)	5.45	7.94	40.7
75% RDN (3S)	5.74	7.90	42.2
75% RDN (4S)	5.88	8.10	42.1
100% RDN (3S)	5.76	8.44	40.6
100% RDN (4S)	5.95	8.74	40.6
50% RDN+NU (2S)	5.52	8.06	40.6
100%RDN	5.42	8.44	39.2
C.D (P=0.05)	0.49	1.52	1.97

Note: RDN is recommended dose of N, 3S is three splits, 4S is four splits, 2S is two sprays and NU is nano-urea sprays

in 4 times was statistically at par with 100% N given in 3 splits. Further, 75% N fertigated in 4 splits showed a marginal edge over 100% N-fertigated in 3 splits. Thus 4-splits applications showed a small benefits, over 3-splits, especially under lower doses of N (50 and 75% RDN). The treds were alike for straw yield too.

The harvest index of wheat was significantly highest with 75% RDN over 100% RDN applied in conventional way, soil incorporation basal followed by two top dressings (Table 1).

The water productivity (WP) in both maize and wheat was found at par among 75% and 100% RDN with 4 splits. However, 50% RDN (4 splits) was found at par with 75 and 100% RDN given in 3 splits for water productivity (Fig. 2). Sidhu *et al.* (2019) reported irrigation water savings of 48–53% in rice and 42–53% in wheat under combination of SSDF and CA compared to flood irrigation system and saving in nitrogen was 20%.

Crop yield have a positive relationship with net photosynthetic rate (Kumari *et al*., 2017**).** All N fertigation treatments showed a higher net photosynthetic rate over control. The Pn was comparable between 50% N subsurface drip fertigated and 100% applied in the conventional

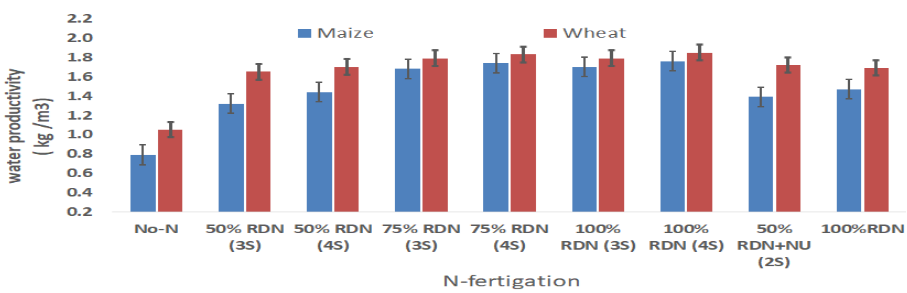

Fig. 2: Water productivity of wheat and maize under sub-surface drip fertigation of nitrogen

way. Fertigating 75% N in 3 or 4 splits recorded significantly higher Pn than 100% N applied in conventional way.

Conclusion

Sub-surface fertigation in maize and wheat crop could be a potential technology for improving productivity, and saving the resources like fertilizer N and water. About 25-50% saving in N is possible in SSDF compared to conventional method of N application. Water saving to the extent of 40% is also possible. Such resource saving has several positive implications on farmers economy and as well as environment.

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Future Sustainability- Eco-systems based Conservation Farming

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Introduction

Humanity is faced with rising demands on natural resources, growing stresses and people's aspirations. In addition, thelarge scale devastation during August-2023,caused by weather and aggravated by anthropogenic factors renewed urgency to the matter. We need innovative solutions including conservation and efficient utilization of water resources, duly highlighted sinceVedic period (S.P. Raychaudhuri and Mira Roy, 1993, ICAR). Recently,H. Liniger of CDE, University of Berne, Switzerland (1995), prioritized interventions in water cycle, prevailing perceptions, relative economics for managing degradation and emerging crisis of water resources. In the context of addressing sustainable development goals relevant to India, "Future Sustainability- Eco-systems based Conservation Farming" is proposed as a major tool.Seven decades of research and watershed development in India have provided strong foundation of conservation of resources, productivity, profitability and sustainability in India.

Currently the North West Himalaya Region is faced with devastating weather. Heavy storms, loss of perennial vegetation, over-exploitation of fragile and vulnerable terrains, absence of soil conservation and drainage line treatments have seriously aggravated the challenges. This has resulted in excessive run-off, severe erosion, slope failures and river side mass-wasting resulted in loss of life and livelihood, dwellings, infrastructure and communication links. Aiming for 2050, transformative management with paradigm shift has to be imparted. These include 5 pillars, 1. Natural Resources and Climate Change; 2. Production Systems; 3. Knowledge and Skills; 4. Demand Scenario and 5. Policy and Livelihood. These could lead to a viableEcosystem based Conservation Farming for future.

Paradigm shift- Objectivity, Specificity, Inclusivity, Efficiency, Viability and Preferred Livelihood: The research and technology development in7 decades have led to environmentally sustainable and profitable production system. Efforts made have resulted in agro- ecosystems and natural resources specific, climate resilient, economically profitable production systems.

Objectivity: Clear objectivity, encompassing the farm families and other stake holders, their stage-wise scaling up, inclusivity of resources, production systems and community, addressing the demand and potential considering the market factors incorporated major paradigm shift.

Conservation of Natural Resources: Encompassing the natural resources, integrating their conservation and efficient management. Inclusive of twin issues of Conservation and drainage,

community and farm production.

Production Systems-Agro-eco systems Specific and demand based: Defined by the characteristics, resources and possibilities, some of these factors like temperature, sun-shine, soil moisture can be managed, whereas many may be beyond the scope of management. Advance Intelligent systems – Market, climate Plant production, nutrient cycling, hydro- cycling.

Production Systems: Arable, Non-Arable, Terrestrial and Aquatic.It also results in diversified resource usage-land, water, aquatic, vegetative inclusive of community. Inclusion of Perennial vegetation- moderates temperature, reduces wind effect, improves rainfall interception instead of their falling on bare surface.

Watershed and appropriate Natural Resources Use Management inclusive of community:

The inclusivity of natural resource management, related production systems over encompassing the ecosystems leads to watershed context. At this stage a management frame work of Watershed level opens up non-arable land use including biofuel possibilities. This may significantly reduce the carbon emission as referred in COP-21, Glasgow.

Natural Resources Status: Components of Hydrologic, Nutrient and Energy cycling, Critical Time

Assessment: Stress, Surplus. These can be comprehensively monitored and assessed at watershed scale.

The skill and capacity based and policy linked journey of farm sector which closely dependent on Market intelligence, adopted a systems approach. It consisted of - Full chain of cause and effect factors –natural resources to agro-ecosystems to production components to Operationalto Harvest management to processing to Market intelligence.

Stages of Erosion, Monitoring and Evaluation: Soil erosion consists Displacement, Transportation and deposition of eroded material.Multi-slot divisor, Stage-level Recorder, V-Notch, Weir, Water harvesting pond, Soil deposit in Trenches, Staff gauges forComprehensive monitoring and assessment of nutrient, water, vegetation and energy cycling in soil erosion.

Ecosystems based Conservation Farming: Seed and varieties, tillage, water and nutrient management, loss prevention, harvest management are major components. Seed to Seed: Pre-sowing, Sowing, Post Sowing, Pre-harvest, Harvest and Post- Harvest.

The Diversified Land uses go with sustainability of Eco-systems and Natural Resource Management, and Economic Viability Leading to area, community, resources market-shed and drainage-systems-water shed approach.

Scaling up: Site; Location: Area , slope, orientation, relief, soil, land-use, moisture regime, community, Market.

Field Plot scale at 0.05 – 0.2 ha: Production systems and Productivity, limited to short term gains, on-site values, resources and implications. Restricted eco-systems range. Limited assessment of area dimensions. Thus, at small scale the management is limited to field and cropping system intensive at individuals and farm family's level.

Farm Holding scale at 0.4- 2.0 ha: Terrain, relief, drainage system, natural resources, agro-ecosystems, Individual farm family level, contract farming. Thus, at holding scale, the management could be at arable and non-arable level with limited aspects of Energy, water, nutrient and carbon cycle.

Micro-Watershed to Village scale at10 -1,000 ha: It encompasses contributing area, receiving area and Draining Area from Ridge to drain. At this scale comprehensive management of natural resources, farming systems, allied activities and terrain inclusive of community can be attempted.

Watershed Scale:

At watershed scale, the cause and effect becomes more comprehensive, the ecosystems, land-use, community, production systems, and on-site and off-site impacts can be well assessed.

Bhagartola Watershed, Jageshwar: This village watershed consisted of 35 families having 12.5 ha of arable and 35ha of non-arable and forest area.

Kakarighat Watershed, Khairna: It included Garh-Syari, Oliya, Okina, Sunya-Kot and Sirauli villages, over 1,500 ha including forest. Revenue area 562 ha. Arable land- 305 ha, Non arable 237 ha. Slope 45%, it's a typical fan-shaped watershed, drained by Kosi River, a part of Ganga Basin located on Bageshwar-Bareilly Highway in Distt. Almora, Uttarakhand.

Aspect: West having North and South Facing flanks.

Watersheds within Regional scale:

North West Himalaya: Uttarakhand, Himachal Pradesh and Jammu and Kashmir, represented by Champawat and Tehri; Chamba; Kupwara and Doda respectively.

Main issues were related to Development, infrastructure and administrative unitsregarding Policies,investment and Interventions.

National Scale: The scientist could scale –up the studies to 102 Aspirational districts of the Country. The selected one include:

- **Hill region:**Resource Conservationaddressed to steep slopes, shallow soils, sun shine related to aspects, temperature and heavy rainfall demands priority management. The off- seasonality and diverse farming holds economic and livelihood potentials.

- **Gangetic Plains Region:**Conservation farming, tapping high production potential and inclusive, demand based high- tech market based farming holds big potential.
- **Plateau Region:**Heavy black and red soil present moisture management challenges. Management of soil erosion, diversified land use and allied activities are a major issue.
- **Forest dominated:**These watersheds have socio-economic and policy constraints. Loss of bio-diversity, unsustainable exploitation of forest and perennial resources are major issues. Suitable model of economic, livelihood and policy development are needed.
- **Flood Dominated:**Theseare aquatic watersheds, having typical environment and livelihood issues. Encroachment, pollution control and Conservation of the water bodies are essential for its sustainability. These ecosystems provide typical livelihood, resource conservation, aquatic farming, economic opportunities and policy issues.

- Knowledge and Skill Development for efficient Farming- an Interface
- Farming as a way of Life-a preferred profession
- Time and Space management
- The Sustainable Livelihoods (Primary Aspects , Secondary Aspects, Tertiary Aspects, Quaternary Aspects, The Synthesis, Social and Economic Aspects-Communities)

Income packages and viable livelihood options

The governing points considered are: Maximising Outputs; Minimising Risk; Imparting Sustainability and Improving Profitability inclusive of Market factors. Soil Conservation Business Model can offer an inclusive frame work to take the endeavor further. It can be expressed as

Eco region / Resource Conditions / Support/ Applicability

Production Systems/Allied Activities/ Domestic, Market needs/Processing / Client specificity

Demand Scenario, Efforts and Emerging Issues

Emerging Demand Scenario and Task: Emerging scenario- life-style purchasing capacity and consumers' awareness. Impact of Infrastructure and economic development results in competing demand on land and water resources requiring comprehensive assessment. Eco-system services emanating from farm sector need to be monetized. On the other hand, mitigating the effects of climate change need management.

Farmers' Knowledge and Skills Development: The advancement of farm knowledge and technology needs serious efforts in imparting these to farming community, beyond the prevailing exercises of few days invariably not going beyond orientation level. Thus, a sort of hybrid system of formal education in Farm Sector has to be evolved for raising the required level of knowledge and skills.

Efforts made and Future Farming Management Systems (FFMS): Efforts made on agro-ecosystems specificity and application of harvested water led to increased production from 5 t, 6 t and 8 t per ha over only 3 t/ha. When scaled up to village level with 37 farm families with water harvesting, fruits, vegetables and fisheries could be integrated. The diversification imparted climate resilience and raised income by INR 130 thousand over < 60thousand/ha /yr.

Scaling up to regional scale over 3,500 farm families; components of drainage line treatments, water harvesting and perennial vegetation to non-arable land over 485 ha, further imparted sustainability, climate resilience and assured livelihood to landless farmers. Adoption of water harvesting, protected cultivation, fisheries, poultry, vegetables and diversified farming over 570 ha, resulted high profitability. Harvested water of > 90,000 m^3 resulted higher income of INR 2,368 th /yr. Allied activities and that of service providing generated employment to youth. Total of 14,800 human days of employment per yrwas generated for 3,500 farm families.

At the National Level (**section 2.6**.); work for 102 disadvantaged districts across the hills, plains, plateau, coastal and forest fringe regions by 36 consortia under ICAR were studied. The author summarised the models, following the path of natural resource management, high productivity, high pay-off production systems, logical intensification and diversification, applied resources, energy, value addition and marketing. This path could lead to very robust and effective **FFMS.**

Policy, Preferred Livelihood and Agenda Next for Future Sustainability:

Policies: Providing basis, parameters and mechanism balancing the causes and effects, integrating the incentive components and enhancing the advantages, equity and long term gains. Specific parameters to the range of ecosystems, resources, market and the communities need. Systematic blend of formal and informal education and skill for farmers required.
Farm families often ignore soil and water conservation in farming and allied activities. The scientists working for soil conservation, farm productivity and site specific challenges, need greater inputs of the on-site experience of our farming communities. **Time for harsh decisions: Strong incentives and dis-incentives.**

Agenda Next: The challenge is how to make soil and water conservation as a way of farming and addressing -what prevents their adoption?

Road map for environmental sustainability, natural resource enhancement, attaining conservation threshold, economic viability and complementary knowledge and skills, and charting the path for 2050, is attempted in preceding sections.

-Terrain conservation and Habitat protection related to Vulnerability Contours and Carrying Capacity on Watershed basis. Resource augmentation need a paradigm shift by Improving the gains, reducing the losses and aiming at augmented status of water, nutrients, vegetation, and soil quality and productivity; thereby reducing the cost and increasing the profit. Integration of traditional with modern knowledge is a key factor for its success and wider adoption.

* Agro-ecosystem based diversified traditional and Organic farming; protected cultivation and Intensive farming, Secondary Agriculture, Wellness and Rural Tourism.

* Value addition, branding and Market interventions. Ensuring Livelihood and Economic
security-Suitable policy, knowledge, skill and investment and community initiatives.

Agenda- Next can be summarized as: Making resource conservation as a way of farming; Quantification, Applicability; Bankability and necessary skills as an enabling policies; Market intelligence; profitability, climate smart farming systems ensuring a respectable farm income. This agenda is expected to lead to Farming as a preferred profession. Thus, 1. Natural Resources and Climate Change; 2. Production Systems; 3. Knowledge and Skills; 4. Demand Scenario and 5. Policy and Livelihood, could lead to a viable **Ecosystem based Conservation Farming for future.**

[1] **Note**

(Studies conducted by- Anil K Srivastva, Manoranjan Kumar, Subhash Chand, Ajay Kumar, K P Singh, D. C. Mishra, K Kaushal and H S Gupta. -2013.)

Assessing the Vertical and Lateral Distribution of some Key Soil Properties in An Agricultural Area of Iran using Digital Maps

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Introduction

Physical and chemical soil properties are the main indicators for evaluating soil quality in agricultural lands (Oliver et al., 2013). The clay content, Calcium carbonate equivalent (CCE), soil acidity (pH) and organic carbon (OC) are indicators of a soil's chemical condition. Therefore, it is necessary to characterize soil conditions for a wide range of crops commonly cultivated in any area (Sys et al., 1993). Furthermore, study of soil organic carbon density (SOCD) is important because it is a crucial property indicating sequestered OC in the soil, thus, a mitigating factor in climate change (Baldock et al., 2012).

Since soil properties vary differently with depth, it is necessary to harmonize their values based on defined interval depths. One protocol is to use the specified depth intervals following the *Global Soil Map* project (0-5, 5-15, 15-30, 30-60, 60-100 and 100-200 cm) which aims to produce a digital soil map at multiple depths (Arrouays et al., 2014). Malone et al. (2017) elucidated a soil depth function in digital soil mapping (DSM) for the matter in Australia.

In addition to DSM, the digital soil assessment (DSA) has been used widely by the fact that it is a substituted system for soil surveying. Moreover, DSA opens a pathway to meet a broad set of requirements in the prediction of key soil properties (Searle et al., 2021). In this case, McBratney et al. (2003) described the *SCORPAN* model to empirically quantify the relationship of a soil property and its spatial distribution. It was numerously used in estimating various soil properties using environmental covariates as easy-to-obtain indices. For instance, Shahbazi and McBratney (2019) applied R programming language using Landsat-8 OLI band ratios for digital soil clay mapping in a field scale in Iran. Lamichhane et al., 2019 also implemented DSM and mapping algorithms as well as covariates for soil organic carbon mapping and their implications in India with success. We finally found that DSM has been shifted from science to applied aspects. In most cases, the data derived from digital elevation model (DEM) and remote sensing (RS) were identified as the most crucial environmental covariates in DSM. A study in India showed that Landsat-8 OLI based spectral indices and terrain parameters were used successfully in digital mapping of SOC, nitrogen and phosphorus (Kalambukattu et al., 2018). The literature showed that extreme gradient boosting (XGBoost) Tree model was faster to train and more accurate than other methods to correlate environmental covariates and soil properties through the DSM (Rahbar Alam Shirazi, 2023).

Finally, the aims of this study were i) to predictive mapping of CCE as an example among the studied key soil properties i.e., clay, CCE, pH, OC and SOCD at five standard depth intervals (0-5, 5-15, 15-30, 30-60, and 60-100 cm) using XGBoost Tree model in an agricultural area (Miandoab region in Iran) thought to be useful in agricultural land suitability in semi-arid region; ii) to demonstrate the ability of easy-to-obtain indices derived from RS and terrain-related attributes relevant to the study area in the prediction of the aforementioned soil properties.

Material and methods

Study area and soil subgroups

This study was performed in Miandoab region (West Azerbaijan Province, Iran) with an area of about 808 km^2. According to the report of IRIMO (2020), the average annual max and min temperatures for the last 15 years are 19.9 °C and 5.7 °C. The identified soil subgroups (USDA, 2014) were Xeric Haplocalcids (363.42 km^2), followed by Typic Calcixerepts (222.73 km^2), Typic Haploxerepts (167.12 km^2) and Gypsic Haploxerepts (54.73 km^2) indicating that Inceptisols were superior than Aridisols across the study area (Fig. 1).

Soil profile data and harmonization

At the first step, a number of 386 soil samples were taken from 104 soil profiles containing three to five layers. The soil samples were analyzed to measure clay (Gee and Or, 2002), CCE (Allison and Moodie, 1965), pH (Thomas, 1996) and OC (Nelson and Sommers, 1996).

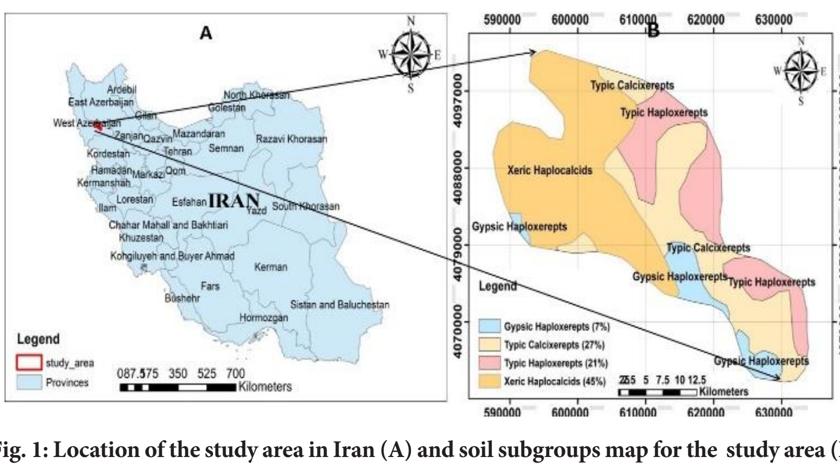

Fig. 1: Location of the study area in Iran (A) and soil subgroups map for the study area (B)

Thereafter, soil organic carbon density (SOCD) was measured using Eq.1 to demonstrate C stock per unit area (Ma et al., 2017). Primarily, it is needed for calculating SOCS. It should be noted that undisturbed samples in addition to disturbed ones were collected from each horizon for bulk density measurement (Blake and Hartge, 1986).

$$SOCD = SOC \times BD \times (h/10) \quad \text{... (1)}$$

$$SOCS = \sum_{i=1}^{n} area_i \times SOCD_i \quad \text{... (2)}$$

where, the unit of SOCD was kg/m^2, and SOC, BD as well as h were soil organic carbon content (g/100g), bulk density (g/cm^3) and horizon thickness (cm), respectively. Furthermore, and were the surface area and the SOCD of the soil subgroup i, respectively. The mean value of SOCS was calculated based on the area of each soil subgroup using the Eq. 2 (Wu et al., 2003).

The next step was to harmonize the original data based on the defined depth intervals. Here, five standard depths (H1: 0-5, H2: 5-15, H3: 15-30, H4: 30-60, and H5: 60-100 cm) were selected. The spline function in R programming language namely "*ea_spline*" within the package of "*ithir*" was used in this research (Perperoglou et al., 2019). With application of the aforementioned function, our soil properties were harmonized according to the defined five standard depth intervals in advance to modelling.

Terrain-related attributes and remotely-sensed data

Environmental covariates as easy-to-obtain indices were used in modelling and for DSM purposes (McBratney et al., 2003) which can be divided into two major types of static (DEM-derived data) (Liang et al., 2021) and dynamic (RS-data) (Mulder et al., 2011). To ease the interpretations, the applied covariates were therefore categorized into nine groups. A similar work was carried out by Sothe et al. (2022) in Canada. Overall, three sets of data (hydrology, lighting, and morphometry) were derived from a DEM with a resolution of 30-m using SAGA GIS. Subsequently, based on the Landsat-8 OLI imagery acquired for July 2019 (close to the sampling date), six sets of data i.e., individual bands (visible bands, near infrared bands, and short-wave infrared bands), vegetation- and soil-related indices as well as geology and moisture-related indices were provided. In summary, a total of 31 covariates were implemented in this research. Those were aligned to the same grid cell resolution (30 m) and extent (EPSG: 32638).

DEM-derive data

The terrain-related attributes used in this study were: I) Hydrology: including topographic wetness index (TWI), catchment area (CAA), modified catchment area (MCA), flow width (FLW), LS-Factor (LSF), and slope length (SLL); II) Lighting group reveal potential incoming solar radiation: including diffuse insolation (DFI) and direct insolation (DRI). We expect that these indices would be suitable in modelling and predictions since slope over the study area varied from gentle to more than 60% (Hofierka and Suri, 2002); and iii) Morphometry: including Elevation (ELE) in a grid system as the main parameter for calculating the indices, Slope (SLP), and its secondary derivatives i.e., aspect (ASP), curvature (CUR), profile and plan curvature (PRC and PLC). The importance of secondary terrain attributes in DSM was reported by Wilson and Gallant (2000). Multiresolution index of valley bottom flatness (MrVBF) and multiresolution index of ridge top of flatness (MrRTF) were also calculated as they were thought to be useful in the prediction of studied key soil properties. Moreover, terrain ruggedness index (TRI) was calculated and applied to quantify the heterogeneity of the terrain (Riley et al., 1999).

Remotely-sensed data

The individual bands are the main sources of acquired Landsat-8 OLI which can be solely used in modelling and for calculating band ratios. Those were classified into three groups i.e., visible bands (B2-B4 corresponding to blue, green and red), B5 (near infrared abbreviated by NIR) and bands 6 as well as 7 (short-wave infrared 1 and 2 abbreviated by SWIR1 and SWIR2). It is obvious that all bands due to different wavelengths are useful for distinguishing soil from vegetation, discriminating vegetation slopes, biomass content and moisture content of soil and vegetation. Normalized difference vegetation index (NDVI), Soil-adjusted vegetation index (SAVI), ratio vegetation index (RVI), grain size index (GSI), and brightness index (BI) are five indices indicating soil and vegetation. Geology-related indices i.e., Clay index and salinity ratio are the two applied indices. Finally, normalized difference moisture index (NDMI) was used as an index in terms of using ancillary data describes the crop's water stress level and varies between -1.0 and +1.0.

Extreme Gradient Boosting Tree model and mapping

Padarian et al. (2020) reported that machine learning algorithms in soil science has been increasingly used, especially in the last 10 years. It facilitated the efficient analysis of soil properties with acquired remote easy-to-obtain data e.g., environmental covariates. Among the commonly used machine learning algorithms (Trontelj ml and Chambers, 2021; Behrens et al., 2018), the extreme gradient boosting (XGBoost) Tree based on their advantages were utilized using R programming to digitally map the vertical and lateral distribution of studied key soil properties over the study area at five standard depth intervals. Since it has been used widely by scientists to achieve state-of-the-art results on a wide range of assessments, it was expected to get an accurate result when using that model. Finally, the vertical and lateral distribution of clay, CCE, pH, OC and SOCD at five standardized depths using XGBoost Tree model were mapped.

Results and discussion

Soil data

Descriptive statistics of key soil properties e.g., clay, CCE, pH, OC and SOCD at five standard depth intervals (H1: 0-5, H2: 5-15, H3: 15-30, H4: 30-60, and H5: 60-100 cm) after fitting the mass-preserving splines to 104 soil profiles were summarized in Table 1. The normality testing using Shapiro-Wilks method showed that, on contrary of pH, the CCE and SOCD data at all standard depths deviates from normality. It was also found that only the data relevant to clay in H3 and H4, as well as OC in H3 were normal. The data were then normalized using square root- and/or log-transformation methods.

Table 1. The summary of descriptive statistics of the studied soil properties (n=104)

Soil properties	min	1stQu	Median	mean	3rdQu	max	Skewness	kurtosis	CV (%)	SD	Sig.
H1: Clay (%)*	8.60	19.49	24.33	26.40	34.55	53.92	0.38	-0.65	41.16	10.86	0.01
H2: Clay (%)*	8.36	19.85	24.05	26.54	34.58	51.87	0.32	-0.73	40.13	10.65	0.01
H3: Clay (%)	7.40	19.90	26.01	27.12	34.79	50.34	0.15	-0.91	38.84	10.53	0.06
H4: Clay (%)	5.11	16.81	28.97	28.66	38.66	65.35	0.17	-0.70	45.33	12.99	0.05
H5: Clay (%)*	1.10	14.33	28.19	28.15	38.80	65.17	0.32	-0.65	54.74	15.41	0.01
H1: CCE (%)**	4.28	8.31	11.03	12.77	14.07	42.12	2.16	4.97	59.04	7.53	0.00
H2: CCE (%)**	4.28	8.51	11.07	12.87	13.98	41.95	2.16	4.91	58.72	7.56	0.00
H3: CCE (%)**	2.58	9.12	11.17	13.27	13.87	44.61	2.08	4.44	59.28	7.87	0.00
H4: CCE (%)**	3.25	9.19	11.52	14.31	16.63	55.06	2.06	4.61	64.16	9.18	0.00
H5: CCE (%)**	3.31	9.47	12.18	14.97	16.65	61.96	2.38	7.13	64.32	9.63	0.00
H1: pH	6.88	7.53	7.78	7.82	8.15	8.71	-0.07	-0.66	5.19	0.40	0.44
H2: pH	6.95	7.55	7.79	7.82	8.13	8.62	-0.11	-0.71	4.88	0.38	0.28
H3: pH	7.15	7.59	7.80	7.82	8.08	8.34	-0.15	-0.87	3.91	0.30	0.09
H4: pH	7.20	7.69	7.84	7.86	8.01	8.63	0.34	0.25	3.37	0.26	0.42
H5: pH	7.30	7.71	7.55	7.92	8.10	9.64	1.58	5.09	4.41	0.35	0.08
H1: OC (g/100g)*	0.03	0.88	1.34	1.39	1.89	3.99	0.71	0.70	50.69	0.70	0.01
H2: OC (g/100g)*	0.03	0.85	1.28	1.34	1.81	3.71	0.63	0.51	49.50	0.66	0.02
H3: OC (g/100g)	0.04	0.74	1.10	1.13	1.46	2.72	0.39	-0.23	47.04	0.53	0.21
H4: OC (g/100g)*	0.06	0.37	0.62	0.69	0.94	1.93	0.71	-0.10	57.25	0.39	0.00
H5: OC (g/100g)*	0.01	0.22	0.38	0.39	0.51	1.07	0.91	0.57	61.53	0.24	0.00
H1: SOCD (kg C/m^2)*	0.07	3.69	5.31	6.13	8.13	14.70	0.73	-0.26	55.77	3.42	0.00
H2: SOCD (kg C/m^2)*	0.10	3.68	5.19	5.97	7.72	13.93	0.74	-0.20	53.29	3.18	0.00
H3: SOCD (kg C/m^2)*	0.23	3.28	4.55	5.32	7.02	16.59	0.99	1.44	52.55	2.79	0.00
H4: SOCD (kg C/m^2)*	0.37	2.06	3.21	3.74	5.12	11.69	0.94	0.68	61.28	2.29	0.00
H5: SOCD (kg C/m^2)*	0.42	1.78	2.64	3.11	3.97	8.67	0.88	0.24	58.10	1.80	0.00

H1: Standardized depth 0-5 cm; H2: standardized depth 5-15 cm; H3: standardized depth 15-30 cm; H4: standardized depth 30-60 cm; H5: standardized depth 60-100 cm; CCE: calcium carbonate equivalent; pH: soil acidity; OC: organic carbon; SOCD: soil organic carbon density; min: minimum; 1stQu: first quartile; 3rdQu: third quartile; max: maximum; CV: coefficient of variation; SD: standard deviation; Sig.: significant value by the method of Shapiro-Wilks (Sh-W).* and **: indicating the distribution of these data deviates from normality and then were normalized by square root- and log- transformation, respectively.

The model validation criteria

Regarding calculated statistical criteria for evaluating the used model both in calibration and validation dataset, there was no bias in the predictions. These analyses were conducted using the normal data and/or square root as well as log-transformed values. Generally, based on the average R^2, the results strongly imply that XGBoost explained 73%, 72%, 70%, 60% and 59% of the total variation for CCE, pH, clay, SOCD and OC, respectively.

In terms of clay, XGBoost Tree predictions were quite good especially in top (R^2=0.78), followed by bottom (R^2=0.71) and middle depths (R^2=0.67). While, for CCE the highest R-squared was identified in the middle (R^2=0.76), followed by bottom (R^2=0.70) and top depths (R^2=0.67). For the rest studied properties, a similar trend was observed. The model performance evaluation revealed that the R^2 values decreased with depth when using XGBoost Tree for predicting pH (R^2: top=0.80; middle= 0.71; bottom= 0.65), OC (R^2: top=0.63; middle= 0.59; bottom= 0.58) and SOCD (R^2: top=0.69; middle= 0.60; bottom= 0.51).

The covariates importance

Figure 2 shows the covariates importance at top (H1) and bottom (H5) depths. A similar monitoring was carried out for the middle depths which was not addressed here.

Digital soil assessment

Notwithstanding there was no available map demonstrating the spatial and vertical distribution of studied key soil properties (clay, CCE, pH, OC and SOCD) at five standard depths (H1: 0-5, H2: 5-15, H3: 15-30, H4: 30-60, and H5: 60-100 cm) in Miandaob region, we

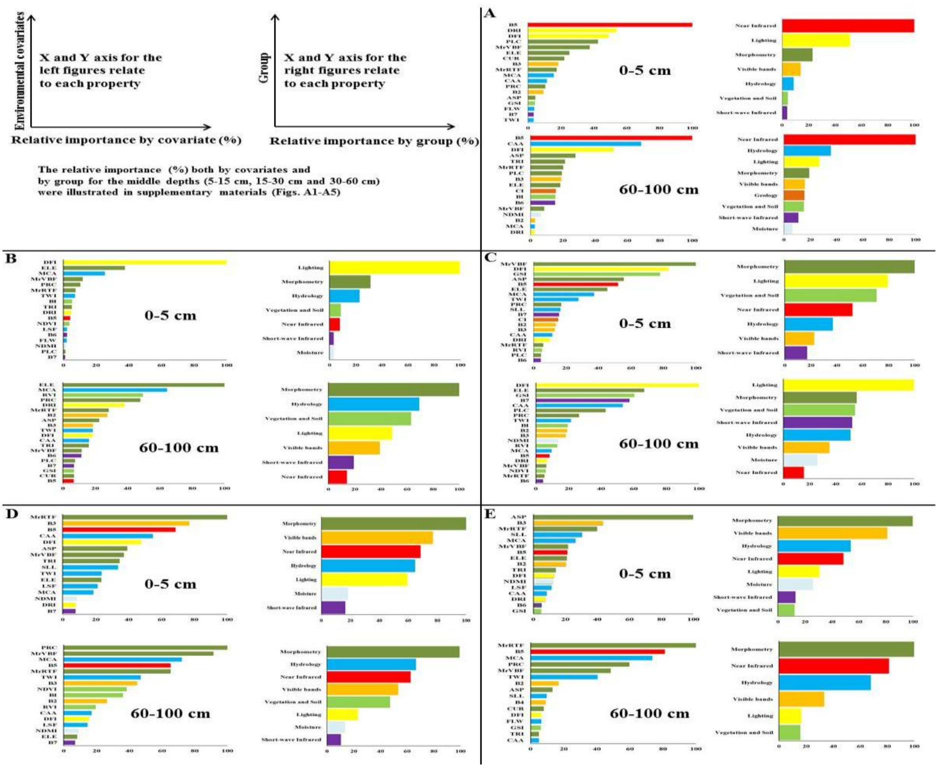

Fig. 2: The importance of covariates used to predict key soil properties at top (H1: 0-5 cm) and bottom layers (H5: 60-100 cm) using Xgb Tree model

prepared the spatial distribution of CCE (Fig. 3) in this paper based on the XGBoost Tree as the best-fitted model. These maps are the back-transformations of the modeled predictions. In terms of clay, it was found that the largest value (on average) was for H5 (30.63%), followed by H4 (30.61%), H3 (27.33%), H2 (25.20%) and H1 (25.02%) indicating an increasing of clay content with depth increments across the study area. Moreover, the spatial variation of soil pH generally shows that notwithstanding there was no more variation on pH (1-fold between their maximum and their minimum values), the western part of the study area at all depths was high in pH compared with the eastern site. Furthermore, the mean pH values relevant to entire study area were increased as soil depth increased. Overall, the entire study area has also a regular decrease in OC content with increasing depth which consistent with the previous findings in arid and semi-arid regions (Taghizadeh-Mehrjardi et al., 2016).

Clay (A); Calcium carbonate equivalent (B); soil acidity (C); organic carbon (D); soil organic carbon density (E); LSF: LS-factor; SLL: slope length; FLW: flow direction; CAA: catchment area; MCA: modified catchment area; TWI: topographic wetness index; DFI: diffuse insolation; DRI: direct insolation; ELE: elevation; ASP: aspect; CUR: curvature; PRC: profile curvature; PLC: plan curvature; MrVBF: multiresolution index of valley bottom flatness; MrRTF; multiresolution index of the ridge top flatness; TRI: Terrain ruggedness index; B2-B7: individual bands derived from Landsat-8 OLI for July 2019 (visible: B2-B4 represent blue, green and red; near infrared: B5; short-wave infrared 1 and 2 represent B6 and B7); NDVI: normalized difference vegetation index; RVI: ratio vegetation index; GSI:

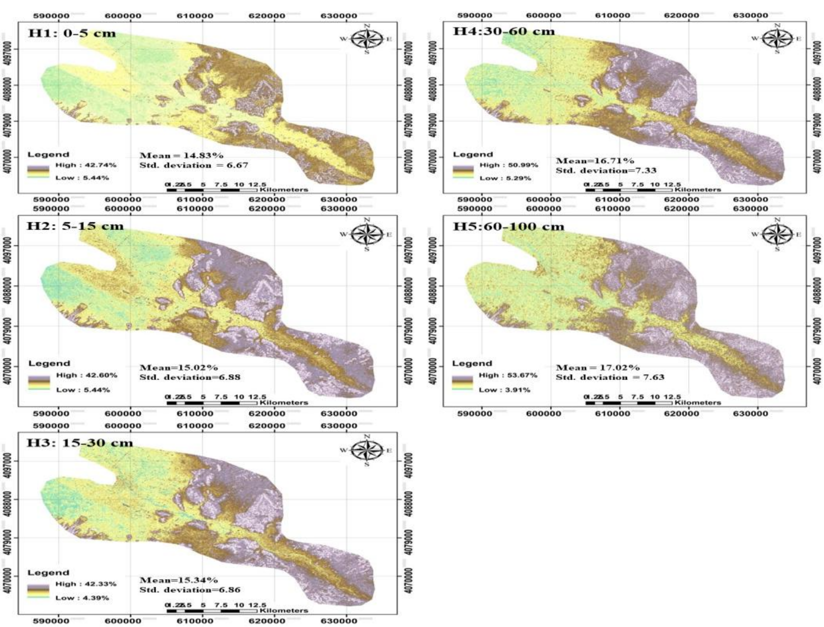

Fig. 3: Predicted maps of CCE (%) across the study area using XGBoost Tree model at five standard depth intervals

grain size index; BI: brightness index; CI: clay index; NDMI: normalized difference moisture index.

In detailed, the highest SOC mean value (in g/100g) was recorded for H1 (1.33) followed by H2 (1.26), H3 (1.13), H4 (0.61) and H5 (0.63). Finally, the spatial distribution maps in terms of SOCD at five standard depths showed that it varies at H1 to H5 depths from 1.47 to 14.81 kg C/m^2, 1.37 to 14.19 kg C/m^2, 0.94 to 10.67 kg C/m^2, 0.29 to 8.49 kg C/m^2 and 0.16 to 6.43 kg C/m^2, respectively. The highest mean value (in kg C/m^2) was recorded for H1 (6.03) followed by H2 (5.85), H3 (4.88), H4 (3.07) and H5 (2.75). The weighted average SOCD for the study area was approximately 3.64 kg C/m^2, indicating that lower than the world's mean SOCD in soil (10.60 kg C/m^2) (Post et al., 1982), mainly due to the extended semi-arid regions. Since understanding the spatial distribution of CCE is essential for sustainable agricultural development in arid lands, Figure 3 shows the digital maps relevant to the spatial distribution of CCE at five standard depths The largest value was for H5 (17.02%, on average), followed by H4 (16.71%, on average), H3 (15.34%, on average), H2 (15.02%, on average) and H1 (14.83%, on average). Such a vertical distribution was expected due to the location of the study area on bedded to massive limestone.

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Model Watershed Planning and Implementation for Effective Resource Conservation and Climate Resilience: An experience from Eastern Ghats, India

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Introduction

Development of watershed/catchment is one of the most trusted and eco-friendly approaches to manage rainwater and other natural resources, which has paid rich dividends in the rain-fed areas and is capable of addressing many natural, social and environmental intricacies (Samra, 1998; Wani et al., 2002, 2003a, b; Rockstorm et al., 2007). Management of natural resources at the catchment/watershed scale produce multiple benefits interms of increasing food production, improving livelihoods, protecting environment, addressing gender and equity issues along with biodiversity concerns (Sharma, 2002; Wani et al., 2003a, b; Joshi et al., 2005; Ahluwalia, 2005; Rockstorm et al., 2007) and is also recommended as the best option to upgrade rain-fed agriculture to meet the growing food demand globally (Rockstorm et al., 2007). This may be the reason why ninth plan document of Govt.of India has accepted watershed as the natural unit for harmonizing synergies of different resources to realize the livelihood aspirations of the agrarian community. This approach offers appropriate planning of natural resources, especially land, water and vegetation to sub- serve the socio-economic and community needs of human society or the community concerned. Hence, watershed planning and implementation foo effective resource conservation and climate resilience is crucial to safeguarding the environment, soil and managing water resources, and adapting to the changing climate (Madhu et al., 2021: Mannivannan et al., 2021).

The Eastern Ghats are discontinuous range of mountains, hills and plateaus on the east coast of India which occupy an area of 19.76 m ha between 77°22; and 85°20' East Longitudes and 11°30' to 21°0'N latitudes spread over the states of Orissa, Chhattisgarh, Andhra Pradesh, Tamil Nadu and Karnataka. Majority of the area of Eastern Ghats falls under Agro-Ecological Zone (AEZ) 12 in northern parts (Sikka et al,2000). The region has predominance of tribals

(54 tribal communities) constituting about 30 percent of the total population of 37.9m (Chauhan, 1998).

Koraput situated in AEZ 12 are quite vulnerable considering morethan fifty percent population as tribal inhabitants along with a sensitive upland habitat plagued with problems of natural resources erosion. Land use practices like shifting cultivation, uncontrolled grazing, large-scale mining, faulty agriculture and over-exploitation of forests having resulted in severe degradation of the region's natural resource base. Frequent and high intensity rainfalls result in various forms of erosion in the area due to lack of or sparse vegetation cover on the rolling topography of the region. High silt production rates (2.07 to 8.96 ham/100sq kms in Koraput region) endanger not only sustainable agriculture but also life of reservoirs in the downstream. Since from ancient period many native tribal practices are highly effective in crop production and well the sustenance of the soil resources (Hombegowda et al., 2021). Erratic rainfall patterns, undulating topography and unfavorable edaphic factors result in unpredictable production systems with extreme cases leading to crop failures. To improve the crop performance in these sloppy areas, practice of conservation measures like contour farming, alley cropping and other SWC measures are very important (Hombegowda et al., 2020: Adhikary et al., 2017).The cultivated land in the region is one-third of the total area, of which only one-fifth is irrigated. Thus, the subsistence agriculture followed is dependent on vagaries of monsoon. The infamous starvation deaths of Kalahandi and Koraput are the results when these frequent crop failures get combined with lack of access. The task is to develop a holistic package for natural resource management for the integrated development of the people in a sustainable, viable and replicable framework.

A model watershed in the tribal dominated areas of Odisha was implemented by ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Sunabeda, Koraput under the MMA, NWDPRA, sponsored by the MoA, GOI, New Delhi. Koraput district (110) is one among the top one-third districts (167) based on high Rainfed Areas Prioritization Index (RAPI) by the NRAA (2012). A comprehensive assessment of LPG watershed was taken up to assess the bio-physical and socioeconomic impacts of various interventions in the watershed. The overall goal of this case study is to get insights into watershed management programs as an implementer and to identify the key components for augmenting the progress and impact on tribes in the rainfed areas.

Watershed Features

Location

Lachhaputraghati (LPG) watershed is located in Pottangi Tehsil of Koraput District in Odisha state. The watershed is 20 km away from Semiliguda town and 45 km away from Koraput District headquarters. The watershed consists of three cluster villages namely Lachhumani, Kandaputraghati and Ariputraghati under Gram Panchayat (GP) Litiguda. The geographical location is 82^o 56' to 82^o 58' E longitude and 19^o 45' 30" to 19^o 47' 30" N latitude with an elevation range of 900 m to 1258 m above msl. The total area of the watershed is about 601.24 ha with undulating to steeply sloping (up to 50%) topography. The order of the watershed is 4th with a drainage density of 7.14 km km^{-2}.

Climate and water balance

The climate of the watershed is warm and humid with an annual mean maximum and minimum temperature of 35.8° C and 7.6° C, respectively. The normal annual rainfall is 1452.2 mm received in 77 rainy days. About 81% of the total rainfall is received during June to September (South-West monsoon). Bright sunshine hours vary from 1.84 to 3.98 and 6.29 to 9.04 during the monsoon and the post monsoon season, respectively. The average evaporation rate is 3.7 mm day^{-1} with maximum in May (6.2 mm day^{-1}) and minimum during the month of August (2.1 mm day^{-1}). Water balance diagram showed that, surplus water is available for agricultural use between the month of May and October with a length of growing period is about 170 days.

Soil and LCC

The soils are red with sandy clay loam in texture. Acidic in reaction, medium in organic carbon (0.69%), soil available nitrogen (288 kg ha^{-1}) and phosphorus content (11.1 kg ha^{-1}) and high in potassium content (313 kg ha^{-1}). The LCC of the watershed revealed that, the maximum area is under class III (43.1%) followed by class VI (22.6%) and class VII (20%). The class II and IV account for 6.6 and 7.7% of the total watershed area, respectively. The class II is under paddy cultivation and the majority of the class III & IV under rain-fed crops of paddy and ragi. Whereas class VI and class VII land is under degraded forest and shifting cultivated area.

Land Use

Out of the total geographical area of 601.24 ha, maximum area is under degraded forest (61%) followed by the net cultivated area (20.15%), current fallow (11.5%), area under non-agricultural use (6.0%) and area under pasture land (1.4%)

SWOT Analysis

Table 1 presents the major strength, weakness, opportunities and threat in the LPG watershed.

Strengths	Weaknesses	Opportunities	Threats
Diversified topographic land features	High soil erosion on sloping lands	Potentials for diversified land use options with conservation measures	Land degradation and declining productivity
A perennial source of water in main streams	Poor water resource development and use of rainwater	Water resource development for increasing crop area and efficient use of rain water	Water scarcity for domestic and agricultural use cause unrest among the community
Existence of strong social integrity among the tribal community	Exploitation by another	Use of participatory approach to development of watershed	Social conflicts due to weak social integrity
Eco-friendly farming with non greedy mentality of the community	Low productivity and nutritional status	Scope for application of best management practices to improve productivity and nutritional security	Vicious cycle and malnutrition which reduces efficiency of work
Well-connected roads and local markets	Exploitation by the middle man and low price for farm produce	Formation of Groups (SHGs & UGs) and establishing market linkages	Community and youths move away from farming due to non-profitability
Presence of various R&D and other developmental organization including programmes and schemes	Poor co-ordination and programme implementation	Scope for convergence approach and establishing co-ordination with other organization.	Credibility on the mandates of various organizations and poor impacts of developmental programmes /projects/schemes

Community organizations, entry point activities and capacity building programmes

Community organization is considered to be an important component of any rural development project. A multidisciplinary team of scientists and technical officers constituted watershed development team (WDT) who conducted several rounds of meeting with the watershed community. Participatory rural appraisal (PRA) exercise was conducted to generate awareness about the project and its mode of operation and execution. Further, exposure visits to successfully executed watersheds were conducted to build confidence of the watershed communities and several entry point activities (EPA) were taken by the WDT in the watershed with the community contributions. Watershed level local people's institutions represented by various sub-communities of the watersheds were constituted for implementation and execution of various watershed development activities (Table 2).

Table 2: Activities taken to generate awareness and community confidence building in the watershed

Activity	Year				Total
	2007-08	2008-09	2009-10	2010-11	
Village meetings	5	3	2	1	11
No to anti-liquor campaign	3	2	1	-	6
Campaign for health and hygiene	3	2	1	-	6
Motivation for enrollment of children in school	1	1	1	1	4
Wall paintings depicting benefits of the watershed programme	12	12	6	-	30
Participation in exhibitions	1	1	1		
Campaign for Saving in bank account	1	1	1	-	3
Newspaper reading	*	*	*	*	

Watershed Development Activities

Various interventions were undertaken in the watershed based on the problems, needs, priorities of the watershed community and their technical suitability and economic viability. The watershed development activities taken in the watersheds are soil and water conservation measures in arable lands, water resource development, productivity enhancement activities, entry point and income generation activities and community organization including capacity building (Table 4).

Monitoring and impact evaluation

Data on bio-physical and socioeconomic parameters were collected through field visits, detailed resource survey, household survey, PRA techniques, meeting, interviews and FGDs during pre-project and post-project implementation of the watershed project. Periodic monitoring and measurement of hydrological, soils, growth parameters and yield of crops,

Table 3: Details of local level institutions at the watershed level

S.No.	People's Institute	No. Group	Total Member	Activity/Role
1	SHGs	15	237	Tailoring, Pickle and sauce making (Household production system), Mushroom farming, Honey production, Cow rearing, Goat rearing and Poultry
2	Watershed Committee	01	13	Overall coordination and liaison, execution of watershed development activities and other activities as per the guideline. WPA: SBI, Damanjodi, Account no. 30863631781. WDFA: UtkalGramaya Bank, Mathalput, Damanjodi bearing account number SBO 164.

Table 4: NRM, production, IGA, EPA and capacity building activities in LPG watershed

S.No.	Activity	Unit	Quantity
I.	**Conservation Measures**		
1	Vegetative filter strips	rm	300
2	Field bunding	ha	32.7
3	Hedge plantation	ha	17
4	Stone bunding	ha	9
5	Trenching	ha	13
II.	**DLT measures**		
1	Live check dam	No	35
2	Brushwood check dam	No	30
3	LBCD	No	44
4	Gabions	No	13
5	Stream Bank stabilization	rm	1124
III.	**Productivity enhancement**		
1	Agri-horticulture system	ha	8
2	Bamboo plantation	ha	1.5
3	Fuel and fodder plantation	ha	2
4	Biodiesel plantation	ha	1.5
5	Silivi-pasture system	ha	1
6	Agronomic interventions	No	7
IV.	**Water Resource Development**		
1	Farm pond	No	6
2	*Jhola kundi*	No	20
3	Renovation of WHS	No	2
4	Renovation of pipeline system	No	1
V	Income generating activities	Group	15
VI	Entry point activities	No	5
VII	Capacity building	No	49

horticultural and forest plants, land use, social and economic parameters were collected. Two gauging stations were installed for runoff monitoring. Siltation behind check dams, DLTs and ponds were also measured periodically at selected places during the implementation phase of the watershed. Besides biophysical data, socioeconomic data in terms of contribution, change in income, income from SHGs, participation of the community in different activities *etc*., were collected through pre-tested questionnaires and interviews

Bio-Physical Impacts

Potential soil erosion rate: Potential soil erosion in the watershed was estimated for pre- (2008) and post- (2012) project period (Figure 1). During the pre-project period, the maximum area under PSER was in the erosion class of >40.0 t ha^{-1} yr^{-1} (20.4%) followed by 15-20 t ha^{-1} yr^{-1} (18.2%) and 10-15 t ha^{-1} yr^{-1} (18.0%) and this was due to the absence of suitable conservation measures and vegetation cover in the watershed. However during the post-project period, the per cent area under high erosion classes (moderate to very high) decreased and these areas shifted towards lower erosion classes (very low and moderately low). This reduction in PSER from higher erosion classes to lower classes was attributed to various conservation measures taken in the watershed which contributed towards reducing the length of slope by field bunding and decreased CP factors due to vegetation cover coupled with bunding and trenching. The average PSER in the watershed for pre and post project period is estimated to 30.24 t ha^{-1} yr^{-1} and 25.03 t ha^{-1} yr^{-1}, respectively (Figure 2). The average actual soil deposited in the trenches was calculated from the silt deposition data and workout to 13.69 t ha^{-1} yr^{-1} of soil was actually arrested on the site otherwise this soil would deposited in the streams and water storage structures.

Runoff: The estimated runoff for different land uses in the watershed varied from 14.68 to 29.92% and 7.3 to 15.4 % for the pre and post project period, respectively (Figure 3). The

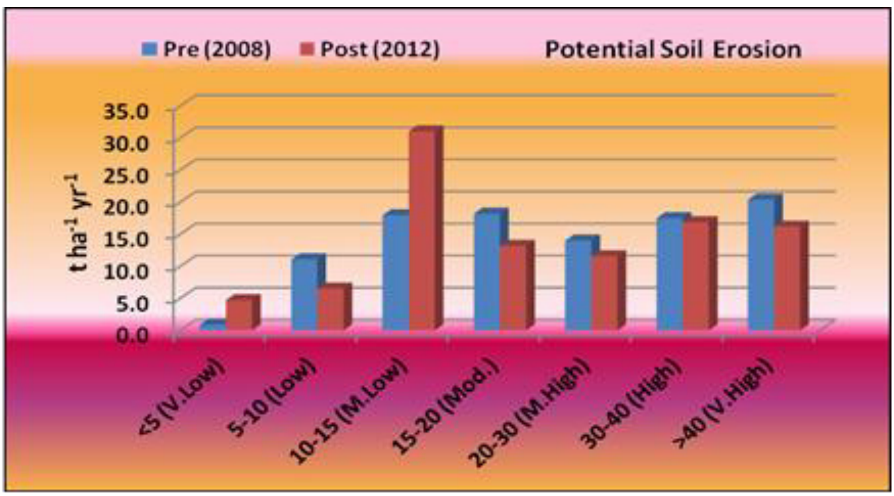

Fig. 1: Potential soil erosion rate during the pre and post project period in the LPG watershed

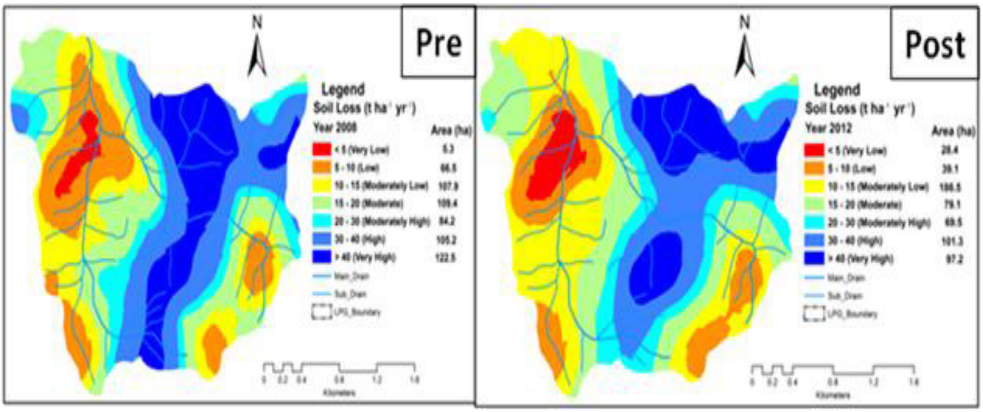

Fig. 2: Potential soil erosion map for pre and post project period in the LPG watershed

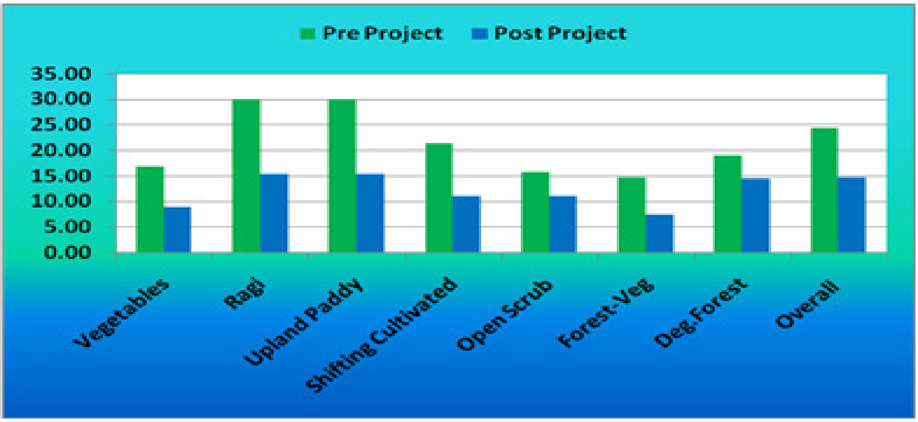

Fig. 3: Estimated runoff under different land use during pre- and post-project period in the watershed.

maximum runoff was observed in upland ragi (29.92%) during pre-project period and it decreased to 15.4% in post-project period due to field bunding in degraded sloping lands. The average estimated runoff in the watershed decreased to 14.6% during post-project period from 24.4% in pre-project period.

Water resource development: The interventions such as dugout ponds, lined ponds, *jholakundi* and check dams were taken up in the watershed to increase the rainwater storage and availability in the watershed. A total of 93.91 ha-cm rainwater storage capacity was created and harvested in the watershed (Figure 4). An additional area of 24.2 ha is brought under protective irrigation for cultivation of paddy and vegetables benefiting 177 beneficiaries in the watershed.

Depth of water table: The average water table depth raised by 0.18 m (5.9%) and the

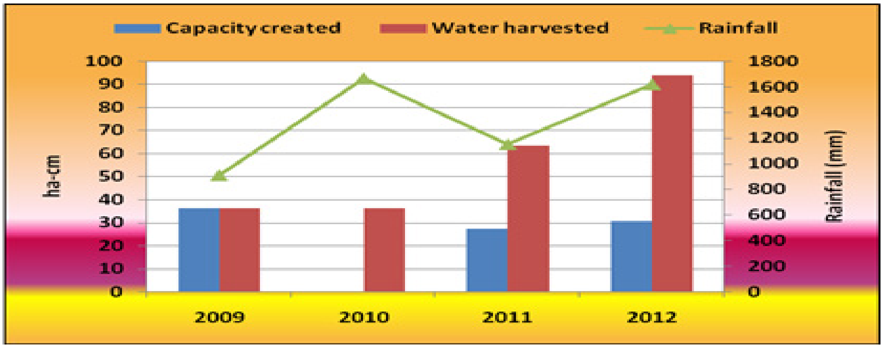

Figure 4: Rainwater storage capacity created and harvested during the project period

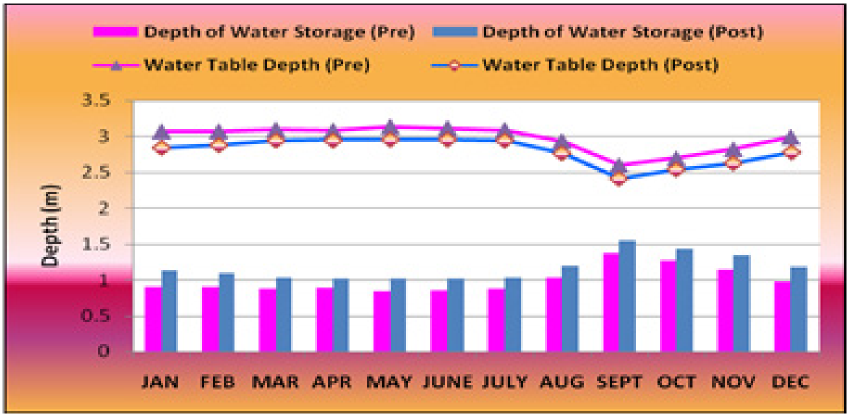

Figure 5: Depth of water storage and water table depth in open well during the pre and post project period in the watershed

depth of water storage in the well increased by 0.17 m (17.8%) during the post-project period compared to pre-project period (Figure 5). The rise in water table depth was more prominent during post monsoon months. The rise in the water table and depth of water storage in the well was attributed to the increased base flow due to soil and water conservation measures in the watershed areas.

Productivity of crops and crop diversification: A total of 45.4 ha area has increased under cereals, pulses and oil seed crops during the project period and similarly area increased under horticultural crops to the extent of 24 ha (Figure 6). The average yield of different crops was collected for pre- and post-project period from the watershed areas and presented in Figure 5.8. The yield of all the crops has increased considerably and in the range of 3 to 15% with the overall average increase of 9.14%

Cultivated land utilization index (CLUI): Cultivated Land Utilization Index was worked out for the period before and after the project. CLUI is calculated by summing the products

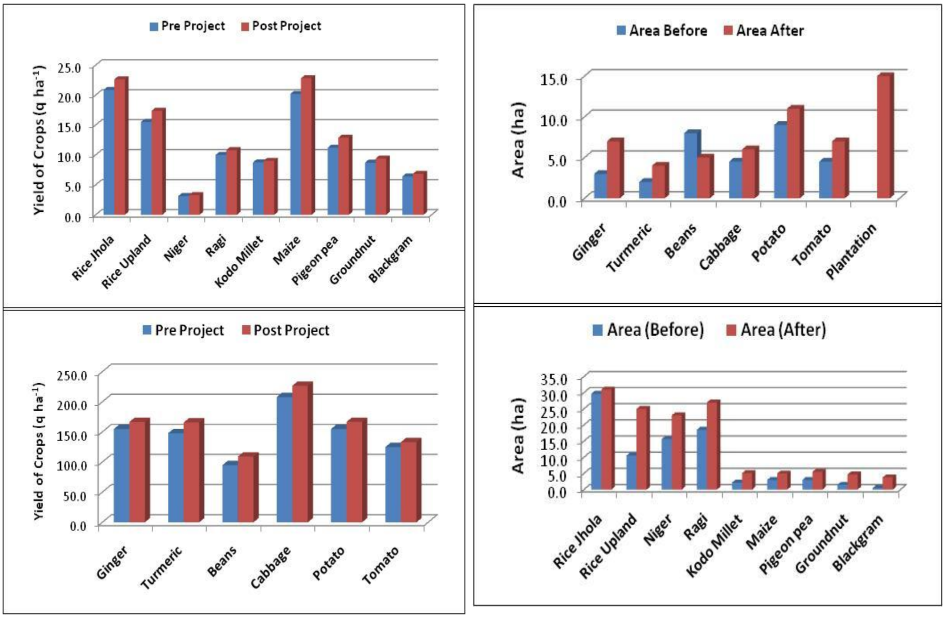

Fig. 6: Area under different crops during pre- and post-project period

of land planted to each crop, multiplied by the actual duration in days of that crop, divided by the total cultivated land area times 365 days. CLUI increased by 0.05 from 0.35 to 0.40 in the watershed areas as a result of the large scale introduction of horticultural plantation in dry land and increased area under irrigation.

Crop productivity index (CPI): Crop Productivity Index indicates the extent of crop productivity level in comparison to the normal yield of crops as per the package of practices. It was calculated by using farmers' yield data and normal yield of crops as per the package of practices to evaluate changes in the productivity level of crops which are grown in the watershed. Overall CPI was increased from 0.547 during the pre-project period to 0.613 after the project, registering an increase of 12% in the productivity level of crops and it was partly due to distribution of inputs viz., seeds and fertilizers.

Crop fertilization index (CFI): Crop Fertilization Index indicates the extent of crop nutrients (NPK) applied to the crop in comparison to the recommended level of nutrients to that crop. Overall CFI increased from 0.21 during the pre-project period to 0.30 after the project, registering an increase of 43% in rate of nutrient application. In general, vegetable crops are fertilized more than the grain crops due to better price for vegetable crops. This was partly due to distribution of inputs during the project period. The CFI is still low indicates that NPK consumption in the watershed areas is very less than half of the recommended dose of nutrients to the crops.

Watershed productivity (WP): Watershed productivity indicates the overall productivity level in the watershed. This was calculated by taking the yield of crops, cropped area and output price of different crops grown in the watershed and expressed in equivalent yield of dominating crops in the area. Overall watershed productivity was expressed in equivalent yield of ragi. The overall WP increased from 4962 kg ha^{-1} of ragi during pre-project period to 6126 kg ha^{-1} after the project period. This was mainly due to increased area under irrigation, slightly increased productivity of crops and diversification of crops towards vegetable crops.

Induced watershed eco-index (IWEI): InducedWatershed Eco Index is used to represent the fraction of green area in the watershed. This represents an additional area made green through watershed treatment as a proportion of the whole watershed area. The value of IWEI observed found to be 0.04, suggesting that an additional 4% of watershed area was rehabilitated through green biomass cover.

Dry land horticulture: Prominent cultivation of mango (*Mangiferaindica*) was introduced in the watershed area. The average overall survival per cent of fruit plants at the end of five years is 68%. Economic analysis was done for a mango plantation under rainfed condition by projecting costs and benefits up to 15 years to know the economic viability. Benefit Cost analysis was carried out at 10, 15 and 20% discount rates. The BCR worked out to be 3.01 and 2.75 at 10 and 15% discount rates, respectively for mango with the Internal Rate of Return (IRR) of 21.28%. Due to Agroforestry interventions, the density of trees, particularly in dry land, increased to 14 trees ha^{-1} from 7 trees ha^{-1}.

In-situ rainwater conservation measures in mango plantation: Soil moisture content was higher at 15-30 cm compared to 0-15 cm in all the treatments. The average soil moisture content at both the depths with mulching was higher by 9.16 (0-15 cm) and 5.56% (15-30 cm) over treatments with no mulching. In general, soil moisture content was high at 0.5 m compared to 1.0 and 2.0 m away from the plant due to *in-situ* rainwater conservation measures. Among the *in-situ* rainwater conservation measures, SCB and SCB with trenching conserved rainwater efficiently in the soil which was reflected in soil moisture content at both the depths. The growth of mango plants was better in all the conservation measures as compared to the control due to increased soil moisture availability in the soil.

Rain water use efficiency and water productivity of crops: Rain water use efficiency of the rain-fed crops is calculated. Maximum RWUE was in the upland paddy (4.49 kg ha^{-1} mm^{-1}) followed by Maize (3.77 kg ha^{-1} mm^{-1}) and low land rice (3.00 kg ha^{-1} mm^{-1}) among the cereals. Among the pulses and oilseeds, RWUE was maximum in Red gram (1.81 kg ha^{-1} mm^{-1}) and groundnut (1.48 kg ha^{-1} mm^{-1}), respectively. Among the vegetable crops, maximum RWUE was in the cabbage (57.4 kg ha^{-1} mm^{-1}) followed by ginger, turmeric and tomato.

Carbon sequestration potential: Total carbon sequestration potential was estimated after the period of 10 and 20 years for different plantations in the watershed areas considering the present survival rate and expected growth rate and stand of each plantation (Figure 7). The maximum carbon sequestration potential is from energy plantation followed by miscellaneous plantation, bio-diesel and Agri-horticulture plantations. A total of 391.24 t and 1114.65 t of carbon sequestration potential is estimated over 10 and 20 years, respectively in the watershed areas. The average carbon sequestration potential is workout to 2.12 and

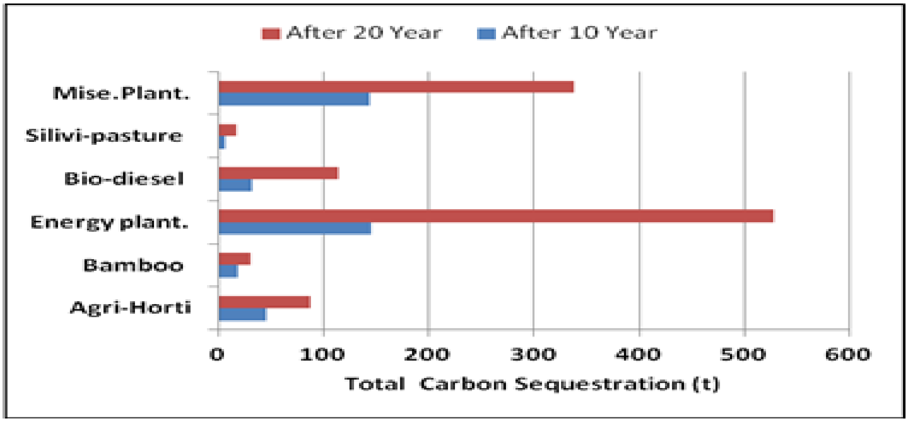

Fig. 7: Estimated total carbon sequestration potential of different plantations

3.4 t ha^{-1} year^{-1} after 10 and 20 years, respectively from the plantation area in the watershed. Estimating the carbon credit at a carbon price of USD 20 t^{-1} of C (Atkinson *et al.*, 2006), it worked out to USD 42.8 (Rs.2544/-) and 68 (Rs.4080/-) ha^{-1} year^{-1} after 10 and 20 years, respectively (1 USD=Rs. 60/-).

Human population carrying capacity: The human population (adult) carrying capacity (HPCC) of cultivated lands in the watershed was worked out as per their production potential during pre and post project period. The HPCC is the ratio of energy output from the land use or production system to the annual energy requirement of an adult. The annual energy requirement for an adult was calculated based on the daily energy requirement recommended by the NIN, Hyderabad (NIN, 2009). The HPCC is lowest in Niger (1.0) and the maximum in potato (12.2). Among the cereals, paddy in *jhola* land, up land paddy and maize have the HPCC of 4.9 to 6.6 during pre-project period and 5.5 to 7.2 during the post-project period. The HPCC of vegetables varied between 2.2 (Beans) and to 12.2 (Potato) during pre-project period and it was increased to 2.4 and 13.1 during the post-project period due to increased in productivity of crops. The average HPCC of crops was increased to 4.4 during post-project period from 4.0 during pre-project period and registered an increase of 9.3% due to enhanced productivity of crops through watershed activities.

Socioeconomic Impacts

People's participation: People's participation in watershed management project is an important index for its sustainability and it measured through People's Participation Index (PPI).The people's participation index was worked out at preparatory phase, watershed work phase and at the consolidation phase of the project. The overall PPI was found to be 56 % indicating that the stake holder's overall participation was just above the medium level. Among the three stages of the project, the level of people's participation was highest (64%) at preparatory phase followed by 58% at work phase and 46% at consolidation phase indicating high to medium level of participation.

Change in income and expenditure pattern: Income expenditure analysis is an important activity which insights into the real development of the watershed populace. The analysis was done before (2008) as well as after (2012) the implementation of watershed projects. The analysis was carried out on the basis of random sampling from all categories of farmers' *viz*. Large, medium and small. The analysis reveals that before the implementation for the project (2008), for large farmers, the source of income was from an array of enterprises *viz*., agriculture, animal husbandry and employment. After the implementation of the project (2012), there is a shift of income from non-institutional finance to agricultural activities to the tune of 5% (Figure 8 and 9). WDT has made efforts in capacity building of all categories of

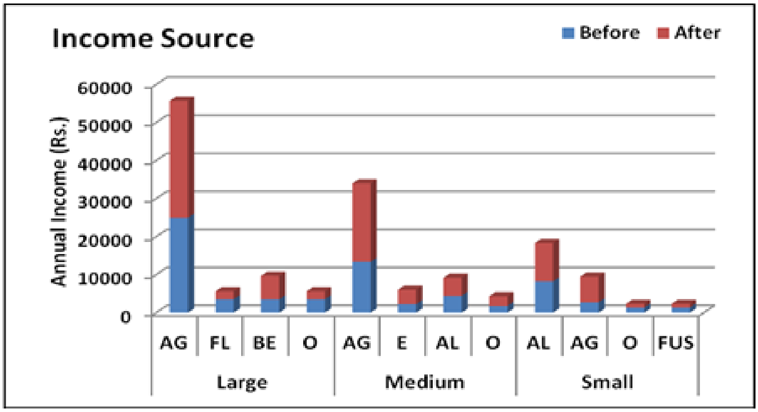

Fig. 8: Source of income under different categories of farmers in the LPG watershed (AG:Agriculture, FL:FinanceLending,BE:Business/ Employment,O: Others, AL:Agri.Labours, FUS:Fuel Wood Sale)

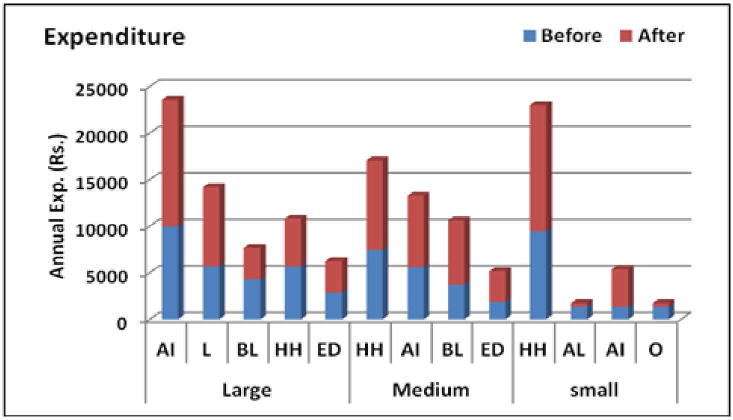

Fig. 9: Expenditure pattern of different categories of farmers in the LPG watershed (AI: Agriculture Inputs, L:Labours, BL: Bank Loan, HH: House Hold, ED: Education,AL:Alcoholism& O: Others)

farmers for different income generation activities. Large farmers showed interest in initiating large scale enterprises *i.e.* poultry and livestock etc. In expenditure analysis, large farmer increase expenditure on inputs procurement and labour work by 5%. However expenditure on food and education remains unchanged.

Employment generation:A total of 14052 man days employment was generated where in maximum employment generation was through water harvesting structures, DLTs and plantation works. Maximum employment generation was during the watershed work phase (84%) followed by a consolidation phase (15.3%) of the watershed development .

5.2.4 Income generating activities for livelihood development: Landless farmers and families hold considerable population (84 families (27%)) of the LPG watershed. To provide seasonal as well as year around income to landless farmers, women and unemployed youths were supported various IGAs in the watershed areas. A total of 221 beneficiaries benefited from these activities. The annual gross income per SHGs varied between Rs.14, 000/- and Rs.40, 000/- (Table 5). On an average the annual gross income (AGI) per beneficiary is Rs.900/-.

Community contribution: Contribution of the community towards watershed activities/ works is considered as a measure of participation. Moreover, contribution in terms of cash and kind enhances the responsibility and commitment to maintain the works and activities created under the project. People came forward enthusiastically to contribute for private as well as Panchayat land in terms of cash and kind showing indication of sustainability of works carried out under the project. A total amount of Rs.1,21,252/-has been received as a contribution under various works in the watershed will be utilized in the post project maintenance of the assets created in the watershed.

Table 5: Details of income generation activities and annual gross returns in the LPG watershed

IGAs	Activity	SHG	Beneficiaries	AGI (Rs. / Group)
Small entrepreneur system	Tailoring	Gramdevi, Swetapadma Mahadevi	33	18,000
Household production system	Pickle and sauce making	Swagatika, Budirani Janani	30	30,000
Biomass based rural industry	Mushroom	Gramdevi, Swagtika, Neelabadi	39	35,000
	Honey Production	Prayas, Brhminbuda Budirani	32	14,000
Dairy activity	Cow rearing	Aakanshya, Shanti	20	35,000
Livestock management	Goats	Kalamgam, Pritam Neelabadi	36	27,000
	Poultry	Maamangla, Janani Sagarika	31	40,000

Convergence activities in the watershed: Watershed management cannot be realized in isolation as it involves different administrative wings of the government. To have an effective watershed management schemes like Rashtriya Krishi Vikas Yojana, MGNREGA, Swarnajayanti Gram SwarozgarYojna (SGSY), Odisha Forestry Sector Development Project (OFSDP) and such other schemes or private players must converge to yield desired results. Need for Convergence Substantial public investments are being made for the strengthening of the rural economy and the livelihood base of the poor, especially the marginalized groups like SC/STs and women.

The economic viability of the project: Economic analysis of the project was carried out for the entire watershed (arable and non-arable) by considering the cost and direct benefits from different activities. The productive life of the watershed project was assumed up to 20 years. The BCR at 10 % discount rate is found to be 1:1.16 and IRR is worked out to be 19.5 % of arable lands. This reveals that the BCR and IRR for arable and non-arable lands suggest the economic viability of the project.

Lessons Learnt

- Socio-cultural-economics of tribal community to be fully understood and respected in the successful implementation of any project and to get community participation and support.
- *Jhola* is a perennial stream fed intensively cultivated (paddy) area on stream bed and either side of the stream which supports the maximum adult carrying capacity among the major land use. Catchment areas to be treated with soil and water conservation measures and vegetation cover for the sustainable water flow in the *jhola*.
- Slopping degraded land (Dunger land) is potential for Agroforestry systems with soil and water conservation measures and water harvesting through silpauline lined ponds for protective irrigation. Major constraint is uncontrolled grazing during the post monsoon season is a bigger threat for successful establishment of plantations. Therefore it is suggested that, cost towards bio-fencing also should be supported by the project for individual land holding.
- The degraded forest lands on high slopes are to be protected and developed through community participation and mechanism of sharing of benefits with the community.
- The tribal community still not convinced with use of micro irrigation systems particularly for high value crops. Required further concentrated effort in this direction in order to improve the rain water use efficiency and productivity.
- Scope for land use diversification and crop diversification in the region with the packaging of conservation and production technologies fully supported by the project or program.

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Prospects and opportunities of Spices, medicinal and Aromatic Plants for Sustenance of Soil and Water Quality in North Eastern Hill Regions

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Introduction

The north eastern region of India comprising the states of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, and Sikkim has vast bio-diversity and is a home to a unique but fragile ecology. It constitutes about 8% of the country's geographical area and 4% of its population. The North- Eastern Region has the total geographical area of 2,62,185 sq. km. Arunachal Pradesh having an area of 83,740 sq. km is the largest state while, Tripura with 10,490 sq. km area is the smallest state of the region. About 70% of the region is hilly and the topography varies within each state. Mountains and hills cover most of Arunachal Pradesh, Manipur, Mizoram, Nagaland, Meghalaya, Sikkim and about half of Tripura, one-fifth of Assam. The rainy season in this region generally commences from March and last till the middle of October. The total annual rainfall varies significantly in the region. In *Khasi* and *Jaintia* hills, the annual intensity of rainfall reaches the maximum of about 1080 cm around Cherrapunjee and Mawsynram (having highest rainfall in the world). It is significantly low in the rain shadow area of Nagaon district in Assam.The north- eastern region is in 6 agro climatic zones. North east region is one of the richest reservoirs of genetic variability and diversity of different crops *i.e.* various kinds of fruits, different vegetables, spices, ornamental plants and medicinal and aromatic plants. The six agro-climatic zones are - Alpine zone (More than3500 meter above sea level/m asl), Temperate and sub- alpine zone (1500-3500 m asl), Sub-tropical hill zone (1000-1500 m asl), Sub-tropical plain zone (400-1000 m asl), Mild-tropical hill zone (200-800 m asl) and Mild-tropical plain zone (0-200 m asl). Characteristics of the North East region and Himalayan state are hilly terrain and poor connectivity and accessibility, extremely fragile ecosystem with huge biodiversity, shifting cultivation (*Jhum*), very small holding and land tenure system, low productivity under traditional cultivation practices, poor industrial base except that of tea, higher literacy with poor employment opportunities, very large number of research and academic facilities has come of late, favourable agro-climate for a wide range of horticultural crops (high humidity and high intensity of light) but only 18% of the cultivated area is under horticulture crops and well distributed rainfall and rich soil (Aishwath, 2022).There are 15,000-20,000 plants have medicinal values inhabitant of north-eastern states either in forest or on warren land. Out of these 7000-7500 plants are used for medicinal purpose by local communities and some of them are cultivated scanty for trade. Though the area of NEH region has fragile ecology even then it has potential for the production of spices, medicinal and aromatic plants at commercial scale(Parthasarthi, 2018 and Aishwath *et al.*, 2018).

Land Use pattern of the regions and prospects of spices, medicinal and aromatic plants

The land use pattern of the area characterise as subsistence agriculture for livelihood security. The land use pattern of the region is strongly influenced by the elevation, climate and mountainous terrain. Forestry is the most dominant land use system followed by agriculture, horticulture, animal husbandry and non-agricultural uses such as urbanization, road constructions, commercial establishments etc. Many of the land use system are found to be hazardous to resources and not conducive to sustained production. The physical geography coupled with precipitation temperature and altitude has a lot towards the diversity and richness of forests of North Eastern part of the country. However, dense forest area is below 60% of the reported area in most of states except Arunachal Pradesh and Mizoram (above 70%) and the net cultivated land is approximately 6.8% only. Except Sikkim and Tripura, all states have the forest cover above 70% of their geographical area. The area put to agricultural use is significantly low in the region compared to all India level of 46.73%. It is highest in Tripura (22.90%) and lowest in Arunachal Pradesh (2.04%). The two important agricultural practices of the region are settled farming practiced in the plains, valleys, terraced foot hills slopes and shifting cultivation in hills. The cropping pattern is rice based and basically subsistence oriented. The geography of the North Eastern region is inverted Bowl Shaped in which the valley region is situated in the middle. The land use capability classification of valley region is somewhat favourable for cultivation (Class–I to Class-IV) whereas the land use capability classification puts the hilly regions in Class-IV to Class-VIII lands that are grossly unsuitable for any type of cultivation of crops (for maintaining the long term sustainability of land resources). Poor and uneducated farmers therefore, are cultivating the uncultivable hilly terrains at the cost of resources sustainability.

Soil resource and its characteristics of NE region

Soil type varied geological, physiographic, climatic and vegetational characteristics have given rise to a variety of soil types in the N-E Himalayas. The National Bureau of Soil Survey and Land Use Planning (NBSSLUP) surveyed the soils of this region and classified the soils into 5 orders, 29 great groups and 71 sub-groups. Inceptisols are the most extensive soil order which cover 11431.5 thousand ha representing 43.60% of the region followed by Entisols by 7040.54 thousand ha (26.85%), Ultisols by 4346.3 thousand ha (16.58%), Alfisols by 1171.5 thousand ha (4.47%) and Mollisols by 81.66 thousand ha (0.31%). Distribution of soil orders indicates that Inceptisols is dominant order in all the states, Ulfisols are second dominant soils in Manipur (36.4%), Meghalaya (40.04%) and Nagaland (23.64%). Mollisols have been identified in Sikkim covering 81.66 thousand ha (14.64%) in middle and lower hills. Thus soils of this region are quite variable depending on the variability of climate, physiography and native vegetation. The depth of soils at different places varies considerably because of differences in physiographic position and slope. Geographical erosion exceeds soil formation except under forest cover. Mass movement of soil in the form of slips, glides, mud flows and solution form are common in this region due to high rainfall, jhuming on sloppy lands, deforestation, faulty methods of cultivation and road construction (Singh 2015).

Soil productivity constraints by chemical degradation in NEH region

The soils of entire region are acidic in reaction caused by heavy rainfall and leaching of bases to lower horizon. As such almost 81, 98, 99.8, 97.2, 99.5, 84.5, and 100 percent soils of Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, respectively have the soil pH below 5.5 and are considered strongly acidic (Table 1). The high temperature at lower altitude and undecomposed organic matter associated with low temperature at higher elevations are responsible for the formation of acidic soils of this humid region. The soils of sloppy uplands are more acidic compared to valley terraced fields as a result of losses of alkali and alkaline metals from the surface soil caused by water erosion and exposure of more acidic sub soil. Aluminium toxicity: Aluminium toxicity is the most important associated problem of acid soils, when pH drops below 5.0. However, the measurements of exchangeable aluminium, the percent aluminium saturation of cation exchange capacity and the concentration of aluminium in the soil solution do not provide consistently suitable criteriafor judging the existence of aluminium toxicity for a given crop species. In the acid soils of NE Himalayan region, the amount of exchangeable aluminium ranged from nil to as high as 7.1 meq/100 g soil of Nagaland (Sen *et al.* 1997) and per cent aluminium saturation up to 85. The aluminium sensitive crops such as wheat, barley, soybean etc may get damage when aluminium saturation of cation exchange capacity exceeds 10% (Patiram *et al.* 1991).

In the rolling topography, soils occurring in the valley bottom are usually waterlogged. Such lands when receive washing of laterites rich in iron create problems. The waterlogged is caused due to underlying clay substratum restricting vertical drainage. Long duration rice in such lands suffers from iron toxicity and bronzing. In addition to iron and aluminium toxicity to plants growing on acid soils, there may be deficiency of nitrogen, phosphorus, calcium, magnesium, molybdenum and boron and toxicity of manganese, which overall imbalance the nutrient status in the soil and plant (Panda, 1987). Microbial activities are reduced in strongly acid soils and aluminium toxicity and deficiency of phosphorus, calcium and molybdenum in legumes leads toadverse effecton Rhizo-bacteria.

Area and production and trade of major spices and MAPs in north eastern states

The North East region including Sikkim is a rich mangrove of spices and has acquired GI tag of spices like Mizo Bird-eye chilli in Mizoram, Naga Mircha in Nagaland, Karbi-Anglong ginger in Assam and large cardamom in Sikkim. Most of the medicinal and aromatic plants in north-eastern states are collected from the forest or the natural habitat. Cultivation of these crops are very scanty or negligible. Currently,major spices (Ginger, turmeric, garlic, chilli and large cardamom) occupying about two lakh hectarearea and getting production around 6-7 lakh ton per year and Medicinal plants species prioritized by SMPB, Assam for trade and cultivation.

Spices cultivation in NEH Region

Among the different spice crops that are grown in the region are ginger, turmeric, chilli and bay leaf. Though recently introduced, the region has a potential for commercial cultivation of black pepper, cumin, large cardamom and saffron. Three commercial crops need mention in this respect *viz.* ginger, turmeric, the local variety 'Lakadong' grown mainly in Jowai area of Meghalaya has shown high curcumin content (7.45%) as compared to 6.7 and 7.2 in high yielding varieties like G.L.Puran and Daghi, respectively. The potential of ginger in NE is huge. Nearly 60% of India's ginger comes from this region. The native ginger from this region has been used by many research institutes and they have taken new avatar in the form of new varieties. The large cardamom (*Amomumsubulatum*Roxb.) is an important spice crop growing abundantly in Sikkim and in some part of Arunachal Pradesh. The total annual production of dry capsules is to the tune of 4,000 tonnes from these states. Some other spices like *A. delabatum* and *A. aromaticum* are also exist. A wild type of *Amomum* known as 'Belak' in Arunachal Pradesh has got very small sized seeds, although the capsules are large. If the astringency of its seed could be reduced, it will find scope for cultivation.

It is generally believed the star anise (*Illeciumverum* L.) is not grown in India. But there are areas in Arunachal Pradesh where the wild relatives of *Illecium*grow wild in the forest. The plant, *Illiciumgriffithii,* found in three districts of the Himalayan state, is a source of shikimic acid, the raw material used to manufacture oseltamivir, an anti-viral drug for influenza. Most of the world's supply of shikimic acid currently comes from China. *Illiciumgriffithii*, locally known as *Lissi*inMonpa dialect, grows in large quantities at an elevation of 2,500 meters and above in Tawang and West Kameng districts. The botanical survey of India recently spotted it in Talle Valley wildlife sanctuary of lower Subansiri district. Studies suggest that this botanical marvel in Arunachal Pradesh had slightly higher levels of shikimic acid than the plants used to extract this chemical in China. A 10.5 per cent level of shikimic acid is sufficient to support commercial viable production. The Arunachal Pradesh variety contains 12 to 14 per cent. This indicates the possibility of growing the commercial star anise in Arunachal Pradesh.

Potential of tree spices in NE region

North eastern states have great potential for large scale cultivation of tree spices due to their varied agro-climatic region, topography and soil. Tree spices like cinnamon, tejpat, nutmeg, curry leaf, allspice, and clove are found growing in small pockets in NER. The region where the temperature does not fall below 15^{0}c has immense potential of growing tree spices commercially. Moreover, NER is famous for the plantation crop like coconut, arecanut, coffee etc. Area under Arecanut in Assam (76.84 thousand ha), Nagaland (0.50 thousand ha), Tripura (4.70 thousand ha) and the area under Coconut in Assam (24.71 thousand ha), Arunachal Pradesh (0.07 thousand ha), Mizoram (0.04 thousand ha), Nagaland (0.33 thousand ha), Tripura (7.13 thousand ha) offer great scope for mixed/inter cropping with tree spices, thereby improving the unit area productivity.

Possibilities of saffron cultivation in North East India

Saffron requires an altitude range from 1500-2400 m. a.m.s.I covered with snow during winter with sub-zero minimum temperatures during December to February to provide necessary chilling of 1100 hrs for commercial cultivation of saffron.

Medicinal and aromatic plants in NEH Region

The report of World Health Organization shows that 80% of world population still depend on traditional medicines as they are efficient, safe, cost effective, affordable and easily accessible by the poor. North-East India is comprised of eight states namely Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim and supports 50% of India's biodiversity. In addition, this region is also a home of 130 major tribal communities. Meghalaya, the abode of clouds, is one of eight sister states of NE India. There are about 3128 species offlowering plants in the state of which 40% of total flora of state is endemic. Meghalaya isendowed with 850 medicinalplants, of which 377 species are used by majority of people fortheir primary health care needs.

Medicinal Plant Species of Assam

In the rural area of Assam people consume many herbs as nutritional diet used inIndian system ofmedicine viz. Bacopa monnieri (L.) Penn., Centella asiatica (L),Dioscorea bulbifera Linn., Emblica officinalis Gaertn, Eryngium foetidum Linn.,Terminalia chebula Retz., Zanthoxylum alatum Roxb., Mentha spicata Linn., Ocimumsanctum Linn., Terminalia bellirica (Gaertn.) Roxb.,Paederia foetida Linn., Euryale feroxSalisb., Solanum nigrum Linn., Piper longum Linn., Garcinia cowa Roxb. Ex D.C.,Garcinia Morella (Gaertn.) Desr., Garcinia pedunculata Roxb., Dillenia indica Linn.,Calamus rotang Linn., Parkia roxburghii G. Don., Alpiniaallughas Rosc., Clerodendrumglandulosum Lindl., etc.Besidesthat about 900 species of medicinal herbs and plants are known to exist in abundance in the forest area of the state with the Brahmaputra valley itself having 50 species of herbs and plants of commercial value. These are Sarpagandha (Rauvolfia serpentina (Benth) ex.Kurz.), Pippali (Piper longum Linn), Amlakhi (Emblicaofficinalis Gaertn), Hilikha (Terminalia chebula Retz.), Bhomora (Terminalia belerica (Gaertn.) Roxb.), Arjuna (Terminalia arjunaWight & Arn.), Vaividang (Embelia ribes Burm.f.), Chaulmoodgra (Hydnocarpus kurzii King.), Mezankori(Litsea citrate Blume.), etc.

Medicinal Plant Species of Arunachal Pradesh

Arunachal Pradesh has 26 major tribes and over 110 subtribes who maintain a close relationship with the nature. The local inhabitants of the state have their own customs, tradition and medicinal system who mainly depended on forests and forest products for their day to day live and medicinal plants used are*Acorus calamus, Ageratum conyzoides, Allium cepa, Allium hookeri, Artemisia indica Berberis wallichiana, Cardamine hirsute, Centella asiatica, Clerodendrum colebrookianum, Crassocephalum crepidioides, Eleusine coracana, Gynostemma pedata*Blume, *Gynura cusimbua, Houttuynia cordata, Siyan hamang, Hydrocotyle javanica, Litsea cubeba, Mahonia napaulensis, Michelia champaca, Mikania micrantha, Molineria Recurvata Oenanthe javanica, Hugu hamang, Oxalis corniculata,, Paederia foetida, Plantago erosa, Plectranthus japonicas, Pteridium revolutum* (Blume), *Rhus javanica Solanum nigrum, Solanum xanthocarpum, Spilanthes paniculata, Swertia chirayita, Taxus wallichiana, Valeriana jatamonsii and Zingiber officinale.*

Medicinal used inManipur

A number ofminor fruits used as medicinal plants by the inhabitants of Manipur are *Aegle marmelos, Annona reticulate, Aphanamixis polystachya, Artocarpus lakoocha, Artocarpus heterophyllus, Averrhoea carambola, Baccaurea ramiflora, Calamus tenuis, Citrus grandis, Citrus macroptera, Dillenia indica, Duchesnea indica, Elaegnus umbellate, Ficus auriculata, Ficus palmate*, *Ficus glomerata*, *Ficus hispida*, *Flacourtia jangomas*, *Gardenia campanulata*, *Garcinia pedunculata*,*Glycosmis arborea*,*Juglans regia*,*Litsea glutinosa*,*Litsea monopetala*,*Malus baccata*,*Meyna laxiflora*,*Musa paradisiaca*,*Olea ferruginea*,*Phyllanthus acidulous*,*Phyllanthus fraternus*,*Prunus domestica* ssp.,*Prunus domestica* ssp. *Rhus chinensis*,*Rubus elliptiens*,*Rubus moluccanus*,*Spondias pinnata* and*Terminalia chebula*

Medicinal plant species used by indigenous people of Sikkim

Medicinal plants are used by the people to cure the ailments are *Abies forrestii*, *Abies webiana*, *Aconitum ferox*, *Aconitum hetrophyllum*, *Acorus calamus*, *Aloe barbadensis*, *Angelica archangelica*, *Artemisia vulgaris*, *Asparagus recemosus*, *Bergenia lingulata*, *Callicarpa macrophylla*, *Celastrus paniculatus*, *Cinnamomum tamala*, *Costus speciosus, Dendrobrium nobile, Eupatorium cannabinum*, *Hedychium spicatum, Mallotus philippinensis, Nardostachya jatamansi*, *Oroxylum indicum*, *Paederia foetida*, *Picrorhiza kurroa,Rubia cordifolia,Swertia chirata, Saussuria lappa,Smilax lanceifolia, Texus baccata, Valeriana hardwickii Zanthoxylum alatum etc.*

Medicinal plants used in Tripura

Aegle marmelos, Ageratum conyzoides,Ananas comosus, Azadirachta indica, Cajanus cajan, Carica papaya, Centella asiatica, Clerodendrum viscosum, Cynodon dactylon, *Jatropha curcas, Kaempferia rotunda, Kalanchoe pinnata, Leucas aspera, Marsilea quadrifolia, Mimosa pudica, Momordica charantia, Musa paradisiaca, Phlogacanthus thyrsiflorus, Psidium guajava, Scoparia dulcis, Spilanthes paniculata, Terminalia chebula*, *Oroxylum indicum*, *Ocimum sanctum etc* are used by tribal people in traditional system of medicine in Tripura.

Soil health management technologies through spices and MAPs.

Green technologies for spices cultivation

Nutrients management plans for spices have been standardized for organic farming system and organic packages have been developed for black pepper, ginger and turmeric integrating composts, oil cakes, bio-fertilizer/PGPRs and bio-control agents, in addition, an entomopathogenic fungus, *Lecanicilliumpsalliotae*, effecting in controlling the cardamom thrips was potentially identified and evaluated at different agro-climatic conditions in Kerala and Karnataka. The technology is ideal for adoption in organic horticulture. Two new spices of entomopathogenic nematodes *viz. Oscheiusgingeri* sp. n. And *Steinernemaramanai* sp. n. are identified as potent biocontrol agents against shoot borer *Conogethespunctiferalis* infesting ginger and turmeric. A new species of group I tetrahedral shaped multiple nucleopolyhedrovirus (NPV) belonging to yhe genus *Alphabaculovirus* of family *Baculoviridae,* infecting *Spilarctia oblique,* a polyphagous pest of ginger, turmeric and other crops was also identified as potential bio-agents.

Spices based cropping system

Spice crops offer great scope for designing cropping system for doubling the farmer's income. Black pepper being a climbing vine, is well adapted to grow as a under crop /mixed crop / intercrop with plantation crops. Humid rainforest ecosystem in the tropical and sub-tropical climate provide appropriate environment for raising annual biennial and perennial crops as inter and mixed crops in high density multi species cropping system. Ginger, turmeric, coffee, banana, cocoyam, and cereals like upland paddy, pulses like red gram, vegetables, flower, fodders and other annuals are intercropped with pepper. Pepper intercropped with coffee, arecanut and coconut. Black pepper can be grown as a suitable and profitable intercrop in areca nut garden under sub-Himalayan *Terai* Region and tea gardens of Assam.

Cardamom, a shade loving plant grown under tall forest shade trees and it offers great scope as a mixed crop in coffee plantation in the tropical forests, besides it can grown under arecanut and coconut plantations, the tree spices such as clove, nutmeg, cinnamon and allspice can inter planted with cardamom.

Ginger and turmeric are intercropped with vegetables, cereals, oilseeds and other crops. These can also be grown as mixed crop with castor, red-gram, finger millet and maize. As these spices requires partial shade, they can be grown as an under crop in coconut, arecanut, rubber, orange, stone fruit, litchi, guava, mango, papaya, loquat, peach, coffee and poplar plantation.

Crop-specific micronutrient formulation for major spices

Majority of soil in the spice growing areas encountering fertility issues due to acidity, nutrients imbalances and deficiencies of secondary and micronutrients that becomes yield limiting. Besides crop specific, soil pH based micronutrient mixtures for foliar application in black pepper, cardamom, ginger, and turmeric crops which guarantees 10 to 25% increase in yield and quality have also been developed. Due to low concentration, an advantage of these mixtures is that they can also be used in organic agriculture and environment friendly way. The technology comes at very low cost and hence is very farmer friendly. The micronutrient technologies have been licensed to several entrepreneurs for large scale production and commercialization. Irrigation of black pepper vines @ 50-60 L/vine at an interval of 15 days can markedly enhance spike length, number of spikes, oleoresin content and berry yield. This technology promotes uniform spike initiation and reduces the spike shedding due to late monsoon and guarantees for good crop.

Spices medicinal and aromatic plants for adverse situations prevail in NE region

1. *Spices, medicinal and aromatic plantsin acid soils*

Almost all the seed spices are fairly tolerable to mild soil acidity and alkalinity while coriander, fenugreek and celery could come up well even up to 5.5 pH level (Fig. 1). It has also been reported that coriander comes well with the soil pH 5.5-8.0 and acid soil is more desirable for both yield and quality (Aishwath *et al*, 2015). Cumin can be grown with pH ranging from 6.8 to 8.3. While, fennel could be grown in heavy clay to sandy loams soils with pH of 6.5-9.0. In case fenugreek, it is cultivated on well drained loams or sandy soils and the acceptable pH rang is 6.0-8.0. The heavy loam or clay with pH 6.0-7.5 is most suitable. Celery thrives well in acid soil but not beyond pH 5.5 and rich in organic matter for both yield and quality. Micro and secondary nutrient are essential otherwise plant shows deficiency symptoms as Boron- Cracked stem, Ca - Black heart and Mg-Chlorosis.Anise requires sandy loam to clay loam soil and pH 6.0-8.5 is well suited to this crop. For nigella, well drained sandy to heavy clay soil acid to alkaline pH is suitable for optimum plant growth. Caraway requires neutral to slightly alkaline soil having pH 6.5-7.5 is most suitable. It shows that these crops have wide adaptability with respect to soil reaction could be fitted into any adverse soil conditions (Aishwath*et al*, 2008). Ginger, turmeric, large cardamom, coriander, anise, star anise, garlic, chilli and bay leaf among the spices are well adoptive to acid soils. However, MAPs listed in table 2, 6 and 7 thrive well in acid soils (Aishwath and Kumar, 2016).

2. *Spices, medicinal and aromatic plants in eroded lands*

Out of total land area, about50.0 per cent is under degraded and cultivated land subjected to serious hazards of water, wind, shifting cultivation, water-logging, salinity and alkalinity and changing water courses. (Narayana and Babu 1983). While seed spices crops and aromatic plants can combat against these problems of erosion on sloppy land. The cultivation of seed spices and aromatic plants like *Anethumsowa*and *Ocimumkilimandscharicum* recommended in degraded habitat orchards as inter-crop (Gupta *et al.* 1998& Narayana 1998).Aromatic grasses on sloppy lands have wide potential for the extraction of oil. In *Cymbopogon species*, *Cymbopoganmartinii* produced oil yield of 68.3kg/ha/year followed by *C winterianus*, 41.3kg/ha/year. At many a places, *Cymbopogons* are utilizing for dual purpose to control the gully erosion and oil extraction in Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat (Verma and Chinnamani, 1998). Similarly, Eucalyptus globules and Eucalyptus robusta utilized in humid regions for dual purpose to control the soil erosion and stabilization of gully erosion as well as essential oil extraction (Ramamohan Rao, 1998). Lavender (*Lavandulaofficinale*) and rose (*Rosadomascena*) could also be grown in sloppy and erodes lands or terraces in hill areas (Shiva *et al*., 2002).Ginger, turmeric, star anise and bay-leaf among the spices could be grown in eroded soils of NEH regions and most of the MAPs listed in table 2, 6 and 7 are adoptive in eroded lands.

3. *Spices and MAPsin nutritionally eroded lands or poor soils*

Fast mineralization of soil organic matter and release of nutrients in soil leads to losses of nutrients through water runoff in sloppy areas. It has been estimated that India is losing about 8.2 million tonnes of nutrients annually (Singh 1998). Erosion of fine soil separates major portion of soil is composed of sand resulting lower retention power of nutrient, high infiltration rate and poor moisture storage capacity. Lower fertility and moisture stress which offer a limited choice for increasing crop production under varying rainfall situation.

4. Spices and MAPs under excess moisture stressor water logged conditions

There has been no accurate estimate of the area afflicted in India under water logging. Framji (1974) reported that nearly 3.5 million hectares areas become waterlogged with the rise in water table in the root zone. Recently, Sehgal *et al*., (1998) reported about 20 million hectares area is under flooding causes water logging. Most of the seed spices are susceptible for the water logging condition. However, water logging or submerged conditions can be utilized for the production of*Acoruscalamus*, while, cardamom (*Elettariacardamomum*) is best suited in swampy areas for its ideal production. Clove can withstand for a shorter period under water logging conditions. In case of kewada (*Pandanus species*), it is highly tolerable to water logging conditions for a longer period. The mint species *Menthaarvensis* is moderately tolerable to water logging for 8-10 dyas provided low atmospheric temperature. However, vetiver is capable of prolong water stagnation and also yielded with full potential (Shiva *et al.*, 2002).Besides above spices and MAPs some of them listed in table 7 and 8 are also boon for water logged areas (Aishwath, 2022).

5. Spices, medicinal and aromatic plants in metal contaminated soils

Most of the NEHR soils are acidic, dissolves the heavy metals and pollutes water bodies/ aquifers. Aromatic crops can provide economic return and metal-free final product, the essential oil.

Horticultural crop plants act as bio-filter for polluted/contaminated water

Some medicinal and aromatic plants act as bio-filters played a great role in removing phosphates, nitrates, nitrites and ammonia. Many substances harmful to human and animals are conducive to plant growth. Plants require ammonia, phosphates and nitrates, and most synthetic fertilizers (as well as laundry detergent) contain these chemicals. However, high concentrations of these chemicals can cause algal bloom or other plant species, disrupting the environmental balance, and sufficiently high concentrations can kill the same plants. Duckweed, nut grass and water lilies are known to absorb these substances. Lily pads are planted in many ponds to control algal blooms. Duckweed expands and spreads as it gains phosphates, as do water lilies. In addition to absorbing chemicals useful to them, certain plants can "lock up" harmful substances such as lead, zinc and cadmium, preventing them from harming other species. These plants can clean-up water up to 99% as a bio-filter.

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Online and Blended Education in Agriculture– A Way Forward

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Introduction

Since time immemorial, Agriculture has contributed significantly to the development of the nation through nutritional security, socio-economic development, employment generation, foreign exchange and so on. Agriculture and allied sectors are the backbone of any nation. In India, agriculture sector not only provides employment to the large masses, but it is the main source of livelihood for more than 80% rural population. Nation building revolves around the growth and development of agriculture and allied sectors, particularly food processing.

Agriculture plays a vital role in India's economy. About 60% of the total workforce is engaged in agriculture and allied sector activities and accounts for 18.6 % of India's Gross Value Added (GVA) at current prices during 2021-22 (MoA, 2022). Keeping in view the importance of agriculture and allied sector, the Government of India has given major thrust to this sector through various initiatives and schemes. The future of any country largely depends on its agriculture sector and hence, improving the socio-economic status of the major stakeholder of this sector i.e., farmers is one of prime importance.To realize the full potential of agriculture, it is important that all stakeholders not only be aware but also have the basic knowledge and understanding of new crop varieties, novel technologies developed for enhancing agriculture production. "Doubling of Farmers' Income" is one such initiative that focusses on higher income for farmers through implementation of various developmental schemes and programmes.

In spite of such valiant efforts by the government, the growth in agriculture and allied sectors is not that encouraging due to various reasons. One of the major factors which can contribute to the growth of agriculture sector is agricultural education and capacity building of farming community. Agriculture education mostly revolves around the Indian Council of Agricultural Research (ICAR). ICAR through its Agriculture Education and Agriculture Extension wings contribute significantly to the human resource development of the agriculture and allied sectors. Agriculture is not a simple subject, it has many disciplines and many agricultural institutions/universities play a vital role in imparting education at the various levels*viz.*awareness, certificate, diploma, degree, masters and doctoral levelsin the various disciplines of agriculture.

Agriculture Education wing plays a pivotal role in developing human resources at graduate, post graduate and doctorate levels, whereas Agriculture Extension wing contributes immensely to the capacity building of the farming community. However, keeping in view the enormous base of the stakeholders, conventional educational system alone will not suffice to fulfill the requirement of human resource development and capacity building. Informal and innovative systems of education like Online, Open and Distance Learning (ODL) and blended learning can bridge this gap.

The agriculture sector has different stakeholders starting from farmers to researchers/ scientists.The educational/training needs of these stakeholders are being fulfilled by the conventional system under ICAR such as Krishi Vigyan Kendras (KVKs), Central and state Agriculture/Veterinary/Fisheries colleges and universities as well as research institutes. Keeping in view the large base of stakeholders in agriculture and allied sectors, informal educational avenues such as ODL, online learning and blended learning modes have to play a pivotal role in order to the caters to the training and educational needs of all the stakeholders. These modes of education may also play a significant role in augmenting the Gross Enrolment Ratio (GER) in agriculture which is negligible currently (around 1%). This paper describes the different modes of agricultural education and consolidate different initiatives promoting online digital and blended education in agriculture sector in India.

Open and Distance Learning in Agriculture

The open and distance mode of education is student centric, flexible, inclusive, cost effective and can contribute in providing educational opportunities to larger community. This can be a most viable mode of education for fulling the educational needs of the disadvantaged sections of the society *viz.* farmers, rural youth, women as well as working class who could not spare time, get opportunity to continue formal education.

There are 14 open state universities and one national Open University in the country catering to the educational needs of the large masses throughout the country as well as abroad. However, only a few of these universities are offering programme in the discipline of agriculture and related disciplines. Table 1 gives a brief about the different programmes in agriculture and allied sectors offered by various open universities in the country.

These institutionshave developed most of these programmes at certificates/diploma at UG and PG levels leading to the human resource development at technician/managerial level, entrepreneurship and continuing education.

As envisaged in the NEP-2020, students can opt for multiple modes for completing their educational requirements and the students have the flexibility to opt for one or more courses through ODL mode. The conventional universities are also focusing on the ODL mode of education by establishing the Directorate of Distance Education (DDE) and offering programme /courses in agriculture and allied sectors.Some of the DDEs established in agricultural/veterinary universities are listed in Table 2.

Table 1: Programmes in agriculture and allied sectors offered by Open Universities in India

S. No.	Name of the Open University	Type of Programmes	Subject
1.	Indira Gandhi National Open University (IGNOU), New Delhi	Masters, UG/ PG Certificate, Diploma, Awareness,	Food Safety and Quality Management, Agri business, Agriculture Policy, Dairy Technology, Meat Technology, Watershed Management, Value Added Products from Fruits & Vegetables, Horticulture, Poultry Farming, Sericulture, Beekeeping, Organic Farming and Water Harvesting & Management, Dairy Farming
2.	Vardhman Mahaveer Open University (VMOU), Kota, Rajasthan	UG/PG Diploma	Poultry Management, Watershed Management, Water Resource Management
3.	Nalanda Open University (NOU). Patna, Bihar	UG Certificate	Medicinal and aromatic plants, Floriculture Technology.
4.	Yashwantrao Chavan Maharashtra Open University (YCMOU), Nashik, Maharashtra	Graduate, UG/ PG Certificate, Diploma	Horticulture, Gardening, Agri Business Management, Agro Journalism, Floriculture & Landscape Gardening, Fruit Production, Horticulture and Vegetable Production
5.	Karnataka State Open University (KSOU), Mysore, Karnataka	UG Certificate	Processing and Value Addition to Fruits and Vegetables, Custom Hiring, Repair & Maintenance of Agricultural Machineries, Seed Production, Bio-fertilizers, Organic Manures, Bio-pesticides and bio-agents production Nursery Management
6.	Netaji Subhas Open University (NSOU), Kolkata, W.B.	UG Certificate	Medicinal and Aromatic Plant Cultivation and Vermicomposting Technology
7.	UP Rajarshi Tandon Open University (UPRTOU), Allahabad, UP	UG Certificate	Dairy Farming, Cultivation of Medicinal & Aromatic Plants and Post Harvest Technology & Value Addition
8.	Uttarakhand Open University, Haldwani, Distt. Nainital, Uttarakhand	Undergraduate, UG Certificate and Diploma	Agribusiness Management, Insurance, Commercial Flower Production, Farm Management, Fish Farming, Mushroom Production, Organic Farming, Vegetable Production, Marketing, Commercial Horticulture, Farm Management and Value Added Product From Fruits & Vegetables
9.	Krishna Kanta Handique State Open University, Guwahati, Assam	Certificate	Scientific and Commercial Broiler Farming, Duck Farming, Layer Farming, Commercial Goat Rearing and Piggery Farming

Online Learning

Government of India has been promoting online education through various initiatives like SWAYAM, SWAYAM Prabha, E-PG Pathshala etc.Online/Digital education has reached the next level during and post-covid wherein many educational institutions have ventured

Table 2: DDEs established in Agriculture/Veterinary Universities in India

S. No.	DDE details
1.	Directorate of Open and Distance Learning, Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu
2.	Directorate of Distance Education, Tamil Nadu Veterinary and Animal Sciences University (TANUVAS), Chennai, Tamil Nadu
3.	Directorate of Distance Education,Kerala Veterinary and Animal Sciences University (KVASU), Pookode, Wayanad, Kerala
4.	Directorate of Distance Education, Annamalai University, Tamil Nadu
5.	Directorate of Extension Education,Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar
6.	Director of Extension Education, Anand Agricultural University,Anand, Gujarat
7.	Directorate of Open and Distance Learning, Assam Agricultural University, Guwahati, Assam

into this domain. Digital Education in India is the way forward to learning and gaining knowledge with the help of technology. Digital education will play a vital role in achieving the targeted GER of 50% by 2030 keeping in view the current population trend in India i.e. more than 50% of its population below the age of 25 and more than 65% below the age of 35 years as per the 2022 data. SWAYAM and SWAYAM PRABHA are the two of the most prominent initiatives of Government of India promoting digital education for large segment of the population particularly disadvantaged groups.

SWAYAM: Study Webs of Active–Learning for Young Aspiring Minds (SWAYAM) is a scheme initiated by the Government of India. The aim of SWAYAM is to achieve the three cardinal principles of Education Policy *viz.*, access, equity and quality. The objective of this effort is to take the best teaching learning resources to the masses. SWAYAM seeks to bridge the digital divide for students who have hitherto remained untouched by the digital revolution and have not been able to join the mainstream of the knowledge economy.

Online education is done through the SWAYAM platformwhich facilitates hosting of various courses starting from Class 9 upto post-graduation. This can be accessed by anyone, anywhere at any time. The courses which are interactive in nature on the SWAYAM platform are prepared by the best teachers in the country and are available free of cost to any learner. The courses are developed at different levels in various disciplines. Nine National Coordinators i.e. All India Council for Technical Education (AICTE), National Programme on Technology Enhanced Learning (NPTEL), University Grants Commission (UGC), Consortium for Educational Communication (CEC), National Council of Educational Research and Training (NCERT), National Institute of Open Schooling (NIOS), Indira Gandhi National Open University (IGNOU), Indian Institute of Management, Bangalore (IIMB) and National Institute of Technical Teachers Training and Research (NITTTR)have been appointed to ensure that best quality contents are produced and delivered.

Steps have been taken to enrich the learning experience by using audio-video and multi-media and state of the art pedagogy / technology.There are 4 quadrants *viz.*(1) video lectures, (2) reading materialsspecially prepared that can be downloaded/printed (3) self-assessment tests (tests and quizzes) and (4) an online discussion forum for interacting with the teacher and peer.

SWAYAM PRABHA: The SWAYAM PRABHA is a group of 280 DTH channels under PM e-Vidyainitiative devoted for telecasting high-quality educational programmes on 24X7 basis using the GSAT-15 satellite. There are three sections in SWAYAM Prabha, (i) School Education, (ii) Higher Education and (iii) Competitive exams. Each section has been allotted a number of dedicated channels to deliver educational content effectively. Twelve channels (one for each class)have been allotted to school education and 40 channels for higher education.

Everyday, there will be new content for at least four hours which would be repeated 5 more times in a day, allowing the students to choose the time of their convenience. The channels are uplinked from BISAG-N, Gandhinagar. The contents are provided by IITs, UGC, CEC, IGNOU. The INFLIBNET Centre maintains the web portal.

Blended Learning

Blended learning,a buzz word, can be defined as combination educational practice of digital learning tools with conventional face to face teaching. Generally, in blended learning, teacher and student should be physically available in the same space during any educational activity or training so that a cohesive environment of learning is developed.

As per the Commonwealth of Learning (CoL), the simplest definition of *blended learning* is "the use of traditional classroom teaching methods together with the use of online learning for the same students studying the same content in the same course". Garrison & Vaughan, (2008) define it as a "thoughtful fusion of face-to-face and online learning experiences".

Sree narayanaguru Open University, Kerala truly applies this concept to fulfill the objectives of the university to provide education in blended mode to people who are unable to attend conventional universities. Sree narayanaguru Open University, the State University located in Kerala aims at strengthening the structural dynamics of academic cooperation for ensuring quality inclusive education and training in blended format for all regardless of age, creed, gender, and religion.

Sathee (Competitive Exam)

This is a Government of India project for Universalization of Quality Education through DTH TV and Web platform. This will cater education & assistance related to study and preparation of college entrance and job oriented competitive exam. It aims to help the students and job aspirants of India at their doorstep i.e.their TV sets. There would be upto 40 channels for this purpose.

Digitization of learning resources (e-Courses)

The Agricultural Education Division, ICAR has institutionalized, upscaled, supported, and enabled the creation of e-Courses for degree programmes in seven disciplines. As per the ICAR approved syllabus, subject matter specialists from the respective disciplines will teach the following disciplines: Agriculture, Fishery Sciences, Dairy Science, Veterinary and Animal Husbandry, Horticulture, Home Science, and Agricultural Engineering.Agricultural students can access the e-Krishi Shiksha Portal on Agriculture Education (e-Krishi Shiksha) online at https://ecourses.icar.gov.in/. MOODLE (Modular Object-Oriented Dynamic Learning Environment) is used to deliver e-courses online, while POODLE (Offline Version of MOODLE) is used to deliver e-courses offline. Courses integrated with POODLE are available on CD-ROMs and DVDs and can be accessed without a computer. All the teachers and students in the field of agricultural education can online access24/7 freeeven in remote areas.Till date, more than 71 lakh views have been made by students and other stakeholders of various AUs.

Consortium for e-Resources in Agriculture (CeRA) *(http://jgateplus.com*)

CeRA is the first of its kind to facilitate 24-hour access to all major journals in agricultural and allied sciences through IP authentication to all researchers, teachers, students, policy planners, administrators and extension specialists in National Agricultural Research System (NARS).It has had a significant impact on the growth of scholarly publications in the field of Agriculture and Allied Sciences.The ICAR research journals' readership has increased by 4-5 folds as a result of their online accessibility and e-publishing system, and article processing time has significantly decreased. Around 142 CeRA member-NARS institutions across India now have online access to almost 3,000 journals thanks to support for access to e-Resources in Agriculture. India's research contribution in the area of agriculture has enhanced thanks to CeRA. Except for 2013, the number of publications in agriculture and biological sciences increased linearly. According to Scimago, the number of publications has grown from 2,845 in 1997 to 14,072 in 2020. Data taken from the Web of Sciences (WoS) revealed a similar pattern. According to Scopus data, the number of articles has climbed from 2,830 in 1997 to 15,506 in 2020.

KrishiKosh *(http://krishikosh.egranth.ac.in/)*

KrishiKosh isanunique repository of knowledge in agriculture and allied scienceswhich captures, preserves, archives, and provides policy-based access to the intellectual output of NARS. It has large collections of old and valuable books, publications, bulletins, project reports, lectures, reprints, records, and various documents available in different libraries of SAUs and ICAR Institutions of the country. Being a digital platform,it helps to preserve institution's intellectual assets and help in providing and managing open access to these literatures. The library currently has more than 2,70,000 items digitized with 50 million pages and caters to the needs of 96 member institutions. More than 175,000 theses have been uploaded by various SAUs, and since April 2017, 23 million researchers from 175 countries have visited the site.

Conclusions

Human resource development is vital for growth of any country. Over the years, conventional mode of education has prevailed, however, the scenario is changing due to the impact of Information and Communication Technology on the mostly young population of India. Our country has witnessed a paradigm shift in the educational system particularly after covid pandemic with a major emphasis on Online/Digital/blended education. The National Education Policy (NEP)-2020 also emphasizes on the multi-disciplinary holistic education through different modes *viz.*, conventional, distance, online learning and blended learning. The online, digital blended education is the only viable, cost effective, flexible, time-saving educational tool. SWAYAM, SWAYAM PRABHA, National Digital Library, e-PG Pathshala, e-shodhsindhu, shodhganga, Vidwan, e-kalpa etc. are the new government initiatives in India for promoting online/digital education.Informal educational avenues such as ODL, online learning and blended learning modes should play a pivotal role in order to cater to the training and educational needs of different stakeholders in agriculture and allied sectors. These modes of education may also play a significant role in augmenting the Gross Enrolment Ratio (GER) in agriculture and allied sector which is negligible currently (around 1%).

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Improving Water Productivity in Arsenic Contaminated Areas of Bihar through Rainwater Harvesting and Efficient Water Delivery Systems

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Abstract

In order to meet the ever growing water requirement in agriculture in Bihar, underground water resources are being stressed beyond their annual recharge capacity leading to a decreasing water table in many areas. Scientific evidence presents a strong rationale for rainwater harvesting and improving the efficiency of water delivery systems in Bihar. Utilization of the existing indigenous irrigation sources (ponds & Ahaar-pynes) can provide a greater impetus towards improving the sustainability of water resources which are being tapped by the faster ground water extraction systems. Lower stress on underground water resources will eventually decongest these and reduce the arsenic load in the food chain. Initiating from selection of crops that are more water responsive and have less water requirement to development and adoption of more water responsive cultivars along with implementation and adoption of water efficient management practice, there is a long way to go for increasing the water productivity in water stressed areas. the pressure on underground water resources can be substantially reduced by enabling and encouraging the communities to enhance surface water resources and use them to meet the water requirements. The pressure on the underground water resources can be reduced largely by augmenting the alternate water sources. The rejuvenation of surface reservoirs and ponds can augment the water supply for the communities. Adoption of efficient water delivery and scheduling mechanisms will increase the productivity of water; so vital for sustaining agricultural productivity. Greater water productivity and ensuring availability of water during critical times makes the communities adapt conveniently to climate change. There is ample merit in demonstration and promotion of scientific rejuvenation of village ponds in Arsenic contaminated villages, efficient water delivery systems in rice-wheat cropping system, and efficient irrigation scheduling in rice-wheat cropping system. Irrigation scheduling in rice wheat cropping system can also increase water use efficiency and substantially increase water productivity. Reducing the number of irrigations and the amount of irrigation water in each instance can potentially result in

more sustainable water use, increase water productivity and reduce overexploitation of water resources. Various strategies to achieve improved water productivity in arsenic contaminated areas of Bihar include pilot implementation of the proposed interventions in some selected arsenic contaminated villages and scientific rejuvenation of ponds in the selected villages with establishment of user groups of the stakeholders.

Hydrologic regime of Bihar in the context of changing climate

Almost one third of the geographical area of Bihar receives on an average less than 750 mm of precipitation annually. Out of the 38 districts of Bihar, 33 of them are considered to be prone to droughts of varying intensities and at varying frequencies. Even the areas flooded during the monsoon season are sometimes affected by drought after the recession of floods. Besides the incidence of drought, the rainy days are often interspersed with long dry spells, sometimes of more than 10 days duration; which adversely affects the agricultural production. Such situations are becoming further complicated in the scenario of climate change, where the incidence or frequency as well as the intensity of extreme weather events such as droughts and dry spells increase substantially. This is to further emphasize that even if there is no meteorological drought, the incidence of agricultural drought results in adverse impacts on agricultural production.

The surface water resources such as Ahar-pynes, village ponds, perennial and seasonal flows in rivers and rivulets are stressed because of pollution, over exploitation, evaporation, and encroachment due to increasing population pressure. Several initiatives such as rainwater harvesting, watershed planning, de siltation of ponds & *Ahar-Pyne* structures and construction of check dams have been thought of to enhance the surface water resources. But these alone are not sufficient. In order to meet the ever growing water requirement in agriculture, the underground water resources are being stressed beyond their annual recharge capacity leading to decreasing water table in many areas. One of the alarming side effects of excess withdrawal of ground water along the lower Gangetic belt has led to elevated arsenic concentration in water, soil, crops, livestock and humans; thus contaminating the whole food chain. The problem of arsenic contamination in the groundwater-soil-plant-animal-human continuum has been confirmed to be geo-genic. Though, there are prophylactic measures for controlling arsenic contamination and toxicity and several agronomic measures have been proposed to mitigate these effects in agriculture, the real solution lies in arresting the movement of arsenic from the deeper zones to the lithospheric soil. Hence, there is a need to reduce the dependence on underground water and use surface waters to the maximum possible, especially in areas where the problem of geo-genic arsenic contaminating the food chain has been reported. The harvested rainwater can then be delivered efficiently through sprinkler or drip systems or applied through efficient schedules for increasing the water productivity.

Rationale for rainwater harvesting and improving the efficiency of water delivery systems

Only about 57 per cent of the gross cultivated area in Bihar is irrigated. Out of the total irrigated area of the state, 30 percent is canal fed which highlights the dependence on monsoons. Ahaar pynes constitute three-fourth of the total irrigation facilities in South

Bihar. More than sixty percent of these are now defunct and the rest of them are poorly managed (Sengupta, 1996)). Although there has been significant private investment in tube wells, the poor state of electricity supply and high cost of diesel act as a limitation for its utilization. In this backdrop, local village ponds qualify as a cheap source of irrigation with a widespread network, notwithstanding their present decrepit condition (World Bank, 2005 and Bhaduri, 2013). Recent trends have been growing on local management of common property resources and development of potential farmer managed irrigation system. Utilization of the existing indigenous irrigation sources (ponds & Ahaar-pynes) can provide a greater impetus towards improving the sustainability of water resources which are being tapped by the faster ground water extraction systems. Rejuvenation of these common farm resources can not only balance the sustainability of water resources but also can be a cheap and an alternative source to the modern exraction systems. Lower stress on underground water resources will eventually decongest these and reduce the arsenic load in the food chain.

The scientific opinion converges on the belief that the resources that can be created by rainwater harvesting are finite and need to be used efficiently for increasing the productivity of water. Initiating from selection of crops that are more water responsive and have less water requirement to development and adoption of more water responsive cultivars along with implementation and adoption of water efficient management practice, there is a long way to go for increasing the water productivity in water stressed areas. Whenever, some water is made available for life saving irrigation through water harvesting or ground water recharge, it is always advisable to use it wisely and ensure that the conveyance losses are kept to a minimum. Hence, there is a need to adopt efficient water delivery systems such as underground water pipes on farms, sprinkler and drip irrigation systems, minimal tillage based cropping, mulching and residue retention etc.

Specific problems that need to be addressed in Arsenic contaminated areas

Stressed underground water resources in Arsenic contaminated areas

By enabling and encouraging the communities to enhance surface water resources and use them to meet the water requirements the pressure on underground water resources can be substantially reduced. This will arrest the lowering of underground water table and keep the arseno-pyrite mineral containing rocks saturated. Ultimately lower arsenic load in the food chain will be a great achievement.

Rejuvenation of surface reservoirs / ponds to augment water resources

The pressure on the underground water resources can be reduced largely by augmenting the alternate water sources. The rejuvenation of surface reservoirs and ponds can augment the water supply for the communities. Rejuvenation of the village ponds has been stressed upon by the NRDMS, Department of Science and Technology, Government of India and a guidebook developed for scientific interventions to rejuvenate the village ponds.

Low water productivity in the scenario of climatic change

Adoption of efficient water delivery and scheduling mechanisms will increase the productivity of water; so vital for sustaining agricultural productivity. Greater water productivity and ensuring availability of water during critical times, makes the communities adapt conveniently to climate change. The incidence of agricultural droughts and dry spells of varying intensities and duration can be mitigated with the availability of life saving irrigation. Further, scheduling irrigation based on the actual requirement of the crop reduces excessive application of irrigation water at times when the crops do not need so much water, thus making the same available during critical periods.

Specific activities that need to be undertaken

Demonstration and promotion of scientific rejuvenation of village ponds in Arsenic contaminated villages of Bihar

The realisation that the scientific rejuvenation of village ponds is possible and the hands on experience with good quality harvested rainwater for irrigation / fertigation along with aesthetic development of the surroundings should lead to adoption of rainwater harvesting and its storage in surface structures. When this happens for several village ponds across several villages, this is bound to reduce the stress on underground water resources. Water filled ponds will not only provide greater livelihood opportunities to the communities but also enable the natural flora and fauna to flourish leading to a vibrant ecology.

Ddemonstration and promotion of efficient water delivery systems in rice-wheat cropping system

Subsurface drip irrigation can be customized in a zero till environment to suit the requirements of rice-wheat cropping system. Such systems have been demonstrated practically at BISA, Ludhiana and at other locations with sustained high water productivity. A wide-scale adoption of such resource conserving technologies will not only reduce the requirement of water but also lead to greater profits resulting from savings in energy expenditure simultaneously leading to adoption of sustainable agricultural practices.

Demonstration and promotion of efficient irrigation scheduling in rice-wheat cropping system

Irrigation scheduling in rice wheat cropping system can also increase water use efficiency and substantially increase water productivity. Reducing the number of irrigations and the amount of irrigation water in each instance can potentially result in more sustainable water use, increase water productivity and reduce overexploitation of water resources. Reducing the number of irrigations also translates into savings on pumping costs and labour costs for farm operations, which is easily conceivable by the farmers.

Promising Strategies to achieve improved water productivity in arsenic contaminated areas of Bihar

- Ex-ante analysis of water productivity and pre-project evaluation.

  The existing practices related to irrigation, in-situ water conservation and maintenance and management of the village ponds shall have to be documented to have a baseline data. The proposed interventions can be evaluated through SWOT analysis and site specific interventions proposed to suit the desired objectives

- Participatory Rural Appraisal

  Participatory rural appraisal helps target technologies as per the need. PRA helps develop a rapport of the investigators with the community following which the messages are conveyed with clarity due to which there is an increased likelihood of the adoption of the targeted technologies.

- Pilot implementation of the proposed interventions in 5 selected arsenic contaminated villages of Bihar.

  Although water harvesting and conservation is a need in all areas of Bihar, these water conservation and water saving technologies are being targeted in areas with reported arsenic contamination because the root cause of arsenic contamination in various districts of Bihar along the lower Gangetic belt is overexploitation of underground water for rice cultivation. This leads to lowering of underground water table and subsequently there is oxidation of the arsenopyrite minerals (if they are in that aquifer) leading to subsequent solubilization of arsenic and its movement to the surface when water is pumped out for irrigation. So targeting arsenic contaminated sites for implementation of this project will be doubly beneficial.

- RS-GIS based survey followed by ground truthing for identification of characteristics of the ponds and surface features of the catchment area.

  In order to achieve successful pond rejuvenation, not only the premises and boundary of the pond need to be treated, but the whole catchment area needs to be identified and treated with need based interventions so that there is minimum silt load in the runoff entering the pond and the runoff entry into the pond is also maximized. A DEM / digital map of the surface characteristics will help in planning the treatments of the catchment area to achieve the desired objective.

- Scientific rejuvenation of ponds in the selected villages with establishment of user groups of the stakeholders.

  Site specific scientific interventions should be identified and implemented at each pond and its catchment in participatory mode with the stakeholders. Hence user groups of the stakeholders shall also have to be created and made responsible for the pond rejuvenation work and subsequently for the equitable distribution of harvested rainwater. Convergence with the existing programmes under Jal Jeevan Hariyaali, if any, in the villages should be promoted

- Capacity building of the communities

  The stakeholders should be trained in upkeep and maintenance of the rejuvenated ponds along with the technologies demonstrated and set up on their farms for further extension and up scaling. The capacity building programmes would need convergence with government departments, financial institutions and panchayati raj institutions for upscaling and sustainable adoption of the technologies demonstrated.

- Set up large plots on farmer's fields falling in the command area of the selected ponds

  Water harvested and stored in the village ponds should be demonstrated to be used through efficient delivery mechanisms and / or irrigation scheduling to increase water productivity in rice-wheat system. Various in situ water conservation practices such as residue management and reduced levels of tillage would also accompany the interventions in the pond catchment area and discussed with the stakeholders for improving water productivity.

- Ex-Post evaluation of the Project

  Towards the end of the project duration, an evaluation of the benefits obtained by the communities, level of adoption and the perception of the stakeholders could be conducted to gauge the effectiveness of the approach and activities.

Target beneficiaries

The rice-wheat farmers in the pond command area will be the direct beneficiaries of the interventions. The project fund would support implementation of the interventions in the pond catchment area, pond peripheries and boundaries, the premises of the pond as well as the demonstrations being set up on the fields of farmers falling in the pond command area in a participatory mode. After completion of the project, the stakeholders would have achieved the capacity to practice the technologies implemented on their fields and would also be able to disseminate them to other farmers. They would also be made aware about the institutional mechanisms that support both financially and technically, the implementation of these interventions on other fields.

Long term benefits will accrue to other farmers who adopt the interventions, either under project support or further with the support of the institutions involved. These are envisaged in terms of greater productivity, reduced arsenic load in the food chain and sustainable environmental management practices. Further benefits are envisaged on a macroeconomic scale with greater water productivity in terms of livelihood opportunities enhancement and greater level of self sustenance in the farms.

Use of Jute Geotextiles as Sustainable Materials in Construction of Low Volume Roads and Slope Embankments

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Introduction

Jute, a natural, eco-friendly biodegradable and annually renewable bast fibre grows abundantly in India and Bangladesh. On an average raw jute production per annum in India is 1.6 million MT. Nearly 7 lakh hectres of land and 4 million farmers are involved in jute cultivation in India. Jute industry in India is one of the oldest agro-industries in the world. More than 0.8 million workers are dependent on jute production, its manufacture and marketing for their livelihood. The matured jute plant with a height of about 3-4 meter is cut and sun dried in the field. The plants with shaded leaves are tied in bundles and immersed in mild flow water for about 2 weeks for retting. The fibres are extracted from the plant, washed in clean water and sun dried to make it ready for use. Jute, known as a golden fibre for its gold-like texture, is a unique textile grade lingo-cellulosic fibre. Its main chemical constituents are given below in Table 1.

Table 1: Main chemical constituents of Jute

	Alfa cellulose	Hemi-celluloses	Lignin	Other matters
Constituents	62 %	24 %	12 %	2 %

Table 2: The physical properties of jute and other fibres

Fibre	Density (gm/cc)	Fineness (denier)	Tenacity (gm/denier)	Elongation at break (%)	Stiffness (gm/denier)	Moisture Content % at 65 % RH
`Jute	1.47	20	4.2	1.2	380	13
Cotton	1.55	2	3.5	8.0	50	8.5
Flax	1.50	12	5.0	2.2	250	–
Kenaf	1.46	27	3.7	1.1	330	12.5
Nylon	1.14	1.5 – 3.0	5.0	15.0	40	4.0
Coir	1.40	162 - 450	1.25 – 1.6	41 - 45	–	10.5

Jute Geotextiles (JGT)

Jute Geotextiles (JGT) is a permeable textile fabric available in woven, non-woven and open weave forms used in or on soil to improve its engineering performance. Woven JGT performs the functions of separation, filtration, initial re-enforcement and drainage when used in the interface of road sub-grade and sub-base, thereby helps soil consolidation and increases the CBR%. Open weave JGT was used for stabilization of slopes in hills and embankments followed by creation of vegetative cover that protects the slopes from destabilization on bio-degradation of JGT. Non-woven JGT is an ideal material for drainage and filtration hence it is suitable as trench drain or cross drain particularly in hilly roads.

Bio-engineering is the technique of utilizing vegetation in addressing geotechnical problems. Environmental uncertainties are prompting engineers to favour bio-engineering measures. Vegetation as an aid to artificial methods in controlling surficial soil erosion is gaining larger acceptability among engineers all over the world. Growth of appropriate vegetation on exposed soil surface is facilitated by use of natural geotextiles such as Jute Geotextiles (JGT). Properly designed JGT laid on slopes or any other exposed soil surface provides a cover over exposed soil lessening the probability of soil detachment and at the same time reduces the velocity of surface run-off, the main agent of soil dissociation. Natural geotextiles bio-degrades quicker than its man-made counterpart but facilitates growth of vegetation quicker and better due to its inherent characteristics. [1]

Table 3

Construction	**Woven JGT (IS 14715 Part I : 2016)**	**Open Weave JGT (IS 14986 : 2001)**			**Standard Method of Test Ref.**
		730 gsm	**500 gsm**	**292 gsm**	
Construction 1/1 DW plain weave	Construction 1/1 DW plain weave	Plain weave	Plain weave	Plain weave	-
Width (cm)	200 cm	122	122	122	IS 1954
Weight (gsm) at 20% MR	724 (Untreated)	730	500	292	IS 14716
Tensile strength (kN/m) MD X CD	25 X 25	12 x 12	10 x 7.9	10 x 10	IS 13162 (Part 5)
Ends X Picks / dm.	94 X 39	7 x 7	6.5x4.5	11x12	IS 1963
Thickness (mm)	1.85	7	5	3	IS 13162 (Part 3)
Elongation at break (%) MD X CD	12 X 12	10 x 12	11 x 15	12 x 12	IS 13162 (Part 5)
Puncture Resistance (kN)	0.500 (± 10%)	-	-	-	IS 13162 (Part 4)
Burst Strength (kPa)	3500 (± 10%)	-	-	-	IS 1966 (Part 1) IS 1966 (Part 2)
Permittivity at 100 mm constant head (m/s)	0.35 (± 10%)	-	-	-	IS 14324
A.O.S. (Micron) O95	150 - 400	-	-	-	IS 14294

Design & Specifications of Jute Geotextile for use in Rural Roads & Slope embankments[1,2]

Functional mechanism of Jute Geotextile

In Road Construction

One of the basic reasons behind road failures is poor drainage conditions coupled with poor soil of the sub-grade. Poor sub-surface drainage in rural roads lead to large amount of costly repairs or replacements long before reaching their design life. JGT have high capability of permitting flow of water across and along plane of fabric (permittivity & transmissivity). JGT acts as a change agent in the consolidation process by triggering gradual development of effective stress within sub-grade and facilitating sub-surface drainage.

Any geotextile performs four basic functions viz., separation, filtration, drainage and initial reinforcement. JGT behaves as a change agent to improve or enhance the geotechnical features of soil on which it is applied by following process occurring concurrently-

- JGT prevents pumping of fine particles/ soils up in coarse base aggregate *(**separation**)*.
- JGT retains soil particles as well as being an hygroscopic material and having high capability of transmissivity and permittivity, absorbs water towards the interface of sub-grade and sub-base, where it is laid, through gravitational and capillary actions and dissipates it, reducing hydrostatic pressure (**filtration and drainage**).
- JGT is designed in such a way that it can resist installation stresses (**initial reinforcement**). JGT provides reinforcement through following mechanisms.

    i. *Membrane support of the wheel loads.*

    ii. *Lateral restraint at the interface of sub-base & sub-grade through combined friction of soil GSB (sub-base) and JGT. JGT exerts confining action on soil*

The right porometry of the fabric in commensurate with the average particle size distribution of soil and initial strength to withstand hydraulic and mechanical loads are the basic requirements of a geotextile that facilitate performance of the four functions as indicated. Jute Geotextile, like its man-made counterpart, can be tailor-made. Soil gains strength in two ways basically—through separation and retention of fines on the one hand and drainage efficiency facilitated by geotextile on the other. It is an accepted understanding that removal of water from soil imparts strength to it. The accepted procedure in soil compaction is to ensure OMC in soil first to achieve maximum dry density in it. It is worth mentioning here that Jute ingredients of Jute Geotextile increase permeability of soil after combining with it. This is a special feature of Jute Geotextile unmatched by other types geotextiles made of other fibres- natural and man-made. Soil treated with Jute Geotextile becomes less dependent on the fabric with the passage of time. Secondly, the loss in strength of Jute Geotextile with time is compensated by corresponding gain in strength of soil under the same time frame. [3,4]

In Slope embankments

Open weave JGT, a three-dimensional fabric when laid on the slope surface initially give protection against erosion by way of dissipation of impact of rain splash and acting as mini check dam due to the presence of thick yarn of the fabric placed across the slope. This check dam retains the dislodged soil particles along with the seeds spread over the slope. JGT as such is excellent drapable fabric, this property is enhanced in wet state. Further, the yarns of fabric swells by around 20% when wet that enables JGT to be more effective to act as check dam. Being hygroscopic in nature JGT creates a moist climate around the soil surface which is conducive to faster growth of vegetation. Within one or two months' time vegetation starts coming up and gradually the function of JGT initially intended becomes less and less necessary. Ultimately after about one year JGT degrade with the soil with the process of bio-degradation and adds nutrients to the soil. In contrast, vegetations are not immediately very effective, but their capacity to retain soil increases as the plants grow and their root and shoot stems develop. When vegetation is fully grown it remains at about 100 percent relative strength. As the relative strength of JGT decreases, the relative strength of the vegetation increases and the soil-retaining function of JGT are handed over to vegetation. [1, 5]

Indian Standards & Guidelines of Jute Geotextile

a. Bureau of Indian Standards (BIS) Standards

i. Guidelines for application of Jute Geo-textiles for rain water erosion control in road & railway embankments and hill slopes(IS 14986:2001)
ii. Guidelines on rural road construction with JGT (IS 14715 Part I : 2016)
iii. Guidelines on river bank protection with JGT (IS 14715 Part II : 2016)
iv. Guidelines for jute sapling bag for growth of sapling in nurseries (IS 16089 : 2013
v. Jute Agrotextiles for growth of plants and suppression of weeds (IS 17070 :2018)

b. Indian Roads Congress (IRC) Code & Publications in India

i. *Guidelines for the Design and Construction of Low Volume Rural Roads Using Jute Geotextiles,* ***IRC :SP:126-2019***
ii. State-of-the Art Report on JGT prepared jointly by CRRI, IJIRA & NJB has been published by Indian Roads Congress in November 2011
iii. Specifications for road & bridge works (2001) & Recommended practice for treatment of embankment slope & erosion control (1991)

c. Research Designs & Standards Organisation (RDSO), Ministry of Railways, Govt. of India –

i. Guideline no GE:G1 (July 2003)—
ii. Guidelines for earthwork in railway projects, 2007
iii. Unified Standard Schedule of Rates (Earthwork in Cutting & Embankment, Bridge Work and P.Way Works)- 2019

Performance evaluation of Jute Geotextiles (JGT) in India & Bangladesh

National Jute Board (NJB) had undertaken a project named as—Development and Application of Potentially Important Jute Geotextiles‖ and under the said project total 12 no.

roads (out of which 7 roads in India and 5 roads in Bangladesh) were constructed using Jute Geotextiles. Time to time performance evaluation of the constructed roads had been done by third party competent Institute like, Indian Institute of Engineering Science and Technology (IIEST), Bangladesh University of Engineering and Technology (BUET),etc. and the obtained results are given in tabular form in Table 4. as under:

Table 4

INDIA					
Road. No	**Name of the Road**	**Soil Type (Pre-work construction)**	**CBR before construc-tion**	**CBR after construc-tion**	**Span of time while the CBR increased**
1.	Udal to Chakbrahma, South Dinajpur, West Bengal	Silty Clay	2.8	11.39	47 months
2.	Nihinagar to Hazratpur, South Dinajpur, West Bengal	Silty Clay	2.2	7.93	47 months
3.	Kanksa to Bati, Murshidabad, West Bengal	Clayey Silt	2.6	7.42	33 months
4.	Bagdimarimulo Barada Nagar to Damkal Kheya Ghat, Mathurapur, South 24 Paraganas, West Bengal	Clayey Silt	3.5	11.11	29 months
5.	Promod Nagar to Muga Chandra Para, Agartala, Tripura	Sandy Loam	8	10.86	19 months
6.	Koracharahatti to T-10 Road, Bidar, Karnataka	Inorganic clays	4	13.4	36 months
7.	Devarahospet to Gundur, Davangere, Karnataka	Inorganic clays	2.8	14.6	36 months
Bangladesh					
Road. No	**Name of the Road**	**Soil Type (Pre-work Construction)**	**CBR before construction**	**CBR after construction**	**Span of time while the CBR increased**
1.	Turag- Rahitpur Bourvita Road	Silty Sand	3 (With JGT) 3 (Without JGT)	13.57 9.64	50 months
2.	Circular Road at Savar Cantonment	Silty Clay	3.6 (With JGT) 3.6 (Without JGT)	12.68 7.61	34 months
3.	Bancharampur southpara, Brahmanbaria	Silty Clay	2.3(With JGT) 2.3 (Without JGT)	13.10 6.50	31 months
4.	Tezkhali- Titas Riverghat Road Brahmanbaria	Clayey Silt	3.3 (With JGT) 3.3 (Without JGT)	8.2 7.7	33 months
5.	Noabanki Shamnagar Road Sathkira	Silty Clay	1.4 (With JGT) 1.4 (Without JGT)	19.80 5	39 months

In 'Figure 1' & 'Figure 2' it is observed that by using the JGT, in rural road construction it has been found that the CBR value is getting increased in India and Bangladesh, which is the primary parameter for load bearing capacity in any road. Hence, the JGT may be strongly recommended to use in case of rural road construction.

Way forward on Jute Geotextiles

National Jute Board (NJB), a statutory body under Ministry of Textiles, Govt. of India, provides technical support and guidance to the manufactures for producing standard quality of JGT, customization of JGT to address site-specific requirements and also provides technical support and guidance in selection of right type of JGT & its installation at site apart from other remedial measures.

Presently NJB is working with National Institute of Technology (NIT) - Durgapur, India,

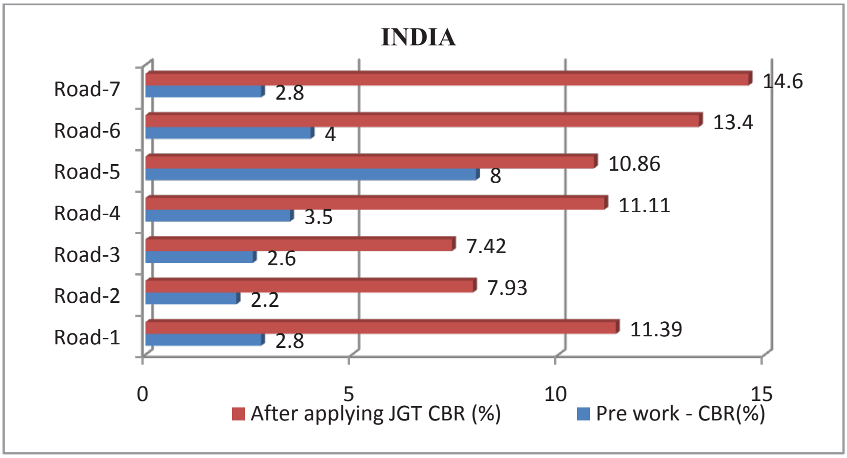

Fig. 1: Increment of CBR (%) value of different road in India

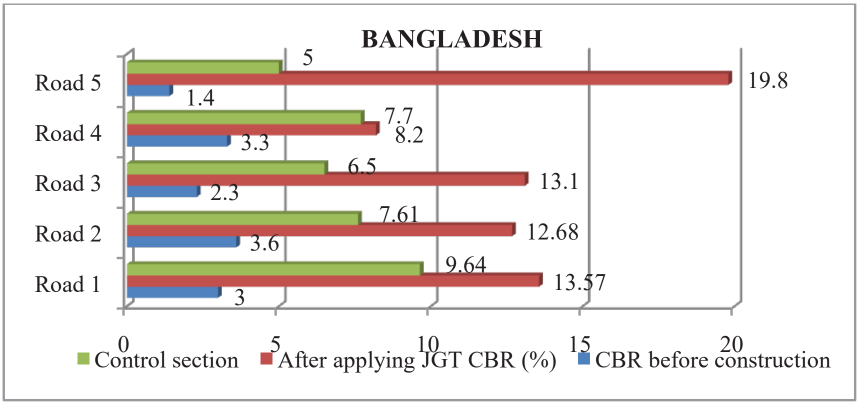

Fig. 2: Increment of CBR (%) value of different road in Bangladesh

Fig. 3: Laying of Jute Geotextiles on sub-grade soil and condition of the road after 2 years

Fig. 4: Laying of Jute Geotextiles for Slope Protection and performance after 6 months

on two projects on—Nano-technological intervention on jute-geotextile to adapt long term sustainability and enhanced durability for its cost-effective and wide application in flexible pavement systemsǁ and —Development of guidelines to adopt the process of height increment of overburden dumps at open cast coal mines in India using jute-geotextile as reinforcing materialǁ to explore further possibilities to enhance durability and supplementary fields for use of JGT.

Conclusions

In this paper, attempts have been made to present observed performance of road using JGT, a natural biodegradable technical textile, it can be interestingly concluded that JGT and soil play mutually supporting roles. Initially, JGT's role is dominant but with passage of time JGT starts degrading and soil becomes self-reliant needing no extraneous support. The CBR value goes on increasing with the continuing process of consolidation of sub-grade till it (consolidation). Consolidation is a protracted process and goes on for years under dynamic load. Use of JGT accentuates the initial process of consolidation by its concurrent functioning of separation, filtration and drainage.

JGT is laid on the shoulder and slope surface helped retain the soil particles and prevented detachment of soil particles from the prepared slope. Establishment of vegetation ensured stabilization of the soil on the slope surface. JGT, a bio-degradable natural geotextile, can conveniently be used for controlling surface soil erosion and help growth of vegetation as a bio-engineering measure. JGT after biodegradation coalesces with the soil and adds nutrient to the soil and fosters growth of vegetation.

The purpose of this paper is to identify effective possibilities for use of jute geotextiles as sustainable materials in construction of low volume roads and slope embankments.

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Doable Agronomic Technologies for Resource Conservation for Sustainable Production in Semi-Arid Tropics of South India

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Introduction

The global food system is expected to provide safe and nutritious food to a population that will likely grow from 7.5 billion people today, to nearly 10 billion by 2050. Not only will there be more mouths to feed, but as incomes grow in emerging and developing economies, so too will the demand for meat, fish, and dairy. Agricultural production is under threat due to climate change in food insecure regions, especially in Asian countries. Various climate-driven extremes, i.e., drought, heat waves, erratic and intense rainfall patterns, storms, floods, and emerging insect pests have adversely affected the livelihood of the farmers. Future climatic predictions showed a significant increase in temperature, and erratic rainfall with higher intensity while variability exists in climatic patterns for climate extremes prediction. For mid-century (2040–2069), it is projected that there will be a rise of 2.2°C-2.8°C temperature in Asian countries. To respond to the adverse effect of climate change scenarios, there is a need to optimize the climate-smart and resilient agricultural practices and technology for sustainable productivity (Habib-ur-Rahman *et al.,* 2022).

Despite the importance of improved technologies in transforming the agricultural sector and improving the welfare of smallholder farmers, access to these technologies remains an issue resulting in inefficiencies in production. Production and development of improved technologies, transfer to, and adoption by farmers is critical in improving the productivity and income of farmers, and ultimately reducing poverty (Adams and Jumpah, 2021 and Wossen *et al.,* 2017). The adoption of improved technologies has a positive and significant effect on the welfare of households (Ayenew *et al.,* 2020). It contributes to improved food security (Justice and Tobias, 2016) and increases the incomes of adopters (Kopalo *et al.,* 2021; Teka and Lee, 2020). Amid expanding dryland biomes in the earth (Yao *et al.,* 2022), achieving food security through resource conservation in arid and semi-arid areas is challenging as it is controlled by many factors, such as agronomic, socio-economic, political and environmental (FAO, 2000 and FAOSTAT, 2019). Among the various factors, modification of adoptive agronomic practices for efficient utilization of environmental resources are important (Tesfuhuney *et al.*, 2023).

Among the adoptive agronomic practices in semi-arid areas modified tillage practices, land configuration such as contour cultivation, scooping, broad-bed and furrow system, conservation furrows, contour and graded border strips, compartmental bunding, ridges and furrows, zing terracing are widely adopted ones (Patil, 1998, Patil *et al.,* 2013 and 2018). Mulching practices such as organic and soil mulch, dust mulch, vertical mulch, sand mulch, plastic mulch are important soil cover practices are being adopted according to the crop demand and various materials combinations are tested for their efficacy in resource conservation (Peng *et al.,* 2019). To improve the soil conditions, adoptable crop residue management, brown manuring, gypsum application and silt application are explored and discussed (Nalatwadmath *et al.,* 2006). Under changing climatic temperature, rainfall and evaporation regimes, soil and water conservation measures at terrace level coupled with inter-terrace are important ones. Runoff harvesting and recycling strategies like farm ponds for supplemental irrigation, efficient surface irrigation methods like border strip, furrow irrigation, sprinkler and drip irrigation are presented with practical field observations. Finally, possible tools of nano technology, hydrophobic and polymers rainwater conservation measures are discussed in the chapter.

Tillage practices

Tillage operations incorporate crop residues, control weeds/pests, diseases, conserve the rainwater *in-situ,* recharge soil profile, and prepare a smooth seedbed for seeds to germinate with a better root system, reduce loss of conserved soil water (secondary tillage) and its efficient utilization for enhanced the crops yield (Patil, 2013; Thyagaraj, 1999). In Alfisols, deep tillage with a plow followed by a cultivator (Channappa, 1994 and Manian *et al.,* 1999) opens the hard layers and increases the infiltration rate with more water availability to the plants during drought situation in the red soils at Bangalore, Karnataka and Coimbatore, Tamil Nadu, India (Table 1). Primary/off-season tillage carried out in Alfisols at ICRISAT and CRIDA, Hyderabad, resulted in better root development in maize& sorghum with greater yields during a drought year (43% increase) compared to a mild drought year (31% increase) and near to the normal rainfall year (24% increase) (Pathak and Laryea, 1995 and Sanghi and Korwar, 1987).

Table 1 Soil water storage in the profile as influenced by deep tillage in red soils.

Depth (cm)	Soil water content (%) (after 81 mm rainfall)	
	Ploughed area	Unploughed area
0-15	10.74	3.59
15-30	13.22	7.13
30-60	12.27	8.59
60-90	13.33	Dry

Source: Channappa, 1994

In the Vertisols of Bijapur, India, deep tillage increased infiltration rate, decreased bulk density conserved higher soil water in the top 0.60 m soil depth, and produced better root development compared to medium and shallow tillage from sowing to harvest in winter sorghum (Table 2). The sorghum yield with deep tillage increased by 27% over medium and 57% over shallow tillage during the drought year compared to an increase in yield by 17% and 34% over medium and shallow tillage during the normal year (Patil and Sheelavantar, 2006). In Vertisols of Ballari, conventional tillage conserved greater rainwater and increased winter sorghum yields by 13% and 8% and sunflower yield by 21% and 33% over reduced and low tillage, respectively (Patil, 2007; Patil, 2013; Patil *et al.* 2013). Similarly, in the Vertisols of Solapur, conventional tillage recorded higher yields of winter sorghum over reduced and low tillage (CRIDA, 2006). The WUE in conventional tillage was higher by 8 to 10% in winter sorghum and 16% to 25% in sunflower over low tillage (Patil and Mishra, 2008). The Conventional tillage was more effective in increasing sorghum, sunflower and chickpea during drought year over reduced tillage red and black soils of Hyderabad, Bijapur and Ballari both at Research farm and farmer's fields (Table 3). Deep tillage with integrated management and improved crop cultivars in the Vertisols (farmer's fields) of Ballari increases the *rabi* sorghum, sunflower and chickpea yields varying from 23-29% over farmers practice depending on

Table. 2: Effect of tillage practices on infiltration rate, bulk density, root growth, and grain yield of winter sorghum in the Vertisols of Bijapur, Karnataka, India

Tillage practices	Infiltration rate (mm h^{-1})	Bulk density (Mg m^{-3})	Root length (cm)	Grain yield (kg ha^{-1})		
				Drought year	Normal year	Pooled
Deep tillage	9.7+0.6	1.23+0.03	67.0	1919	1835	1877
Medium tillage	8.0+0.5	1.27+0.02	57.6	1509	1562	1635
Shallow tillage	6.1+0.7	1.31+0.05	41.7	1223	1368	1296
LSD (P=0.05)	–	–	–	164	186	103

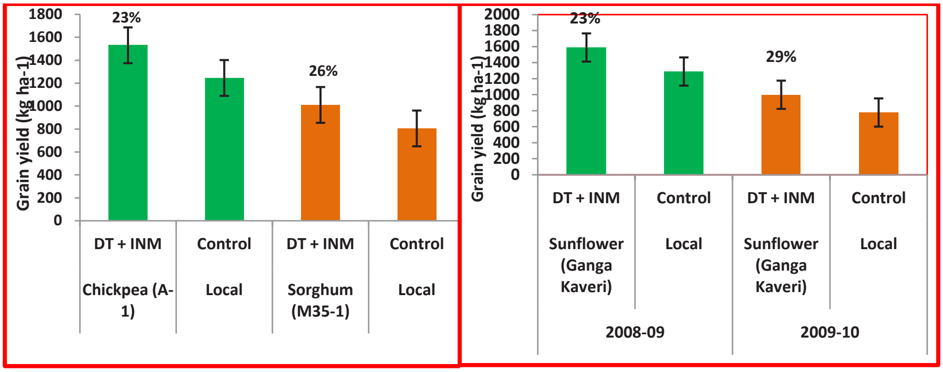
Source: Patil and Sheelavantar, (2006)

Table 3: Effect of conventional and reduced tillage on sorghum grain yield (kg ha^{-1}) in south India under different rainfall and soils.

Tillage System	Hyderabad		Bijapur		Ballari Black Soils					
	Sorghum		Sorghum		Sorghum			Sunflower		Chickpea
	Red Soils		Black Soils		Research Farm			Farmers' fields		
	NY	DY	NY	DY	NY	DY	DY	NY	DY	DY
No offseason tillage/ Reduced tillage	1950	993	1368	1223	2221	819	1010	1590	1000	1530
Offseason tillage/ Conventional tillage	2430	1651	1835	1919	1936	738	805	1290	778	1245
Per cent increase	**24**	**66**	**34**	**57**	**15**	**11**	**26**	**23**	**29**	**23**

NY: Normal year; DY: Drought year

rainfall indicating the importance of improved technologies over farmers practice (Fig. 1) (Nalatwadmath, S.K. and Patil, S.L., 2010).



Chickpea and *Rabi* Sorghum **Sunflower**

Fig. 1: Deep tillage, integrated nutrient management and improved crop cultivars on crop yields in Vertisols of Ballari in the farmer's fields.

Land Configuration

After the execution of soil conservation structures in the field, it's essential to take up land smoothing in the inter-bund area to enable the rainwater to spread uniformly in the field so that it recharges the soil profile. These modified land configurations are effective *in-situ* rainwater conservation measures, particularly in low rainfall areas, and are discussed below.

Contour cultivation

Contour cultivation in the red soils of the Kabbalanala watershed near Bangalore reduced runoff and soil loss conserving rainwater *in-situ*, and increasing soil moisture in the profile and crop yields of sesamum, fingermillet, and groundnut over farmers' practice (Fig. 2) The effect of contour cultivation was more felt when crops were supplemented with NPK

Fig. 2: Contour cultivation

Source: Pathak et al. (2009)

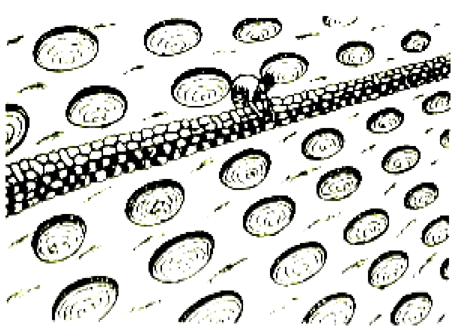


Fig. 3: Scooping in black soils

fertilizers (Krishnappa et al., 1994 and 1999) (Table 4). Contour cultivation produced 35% and 22% higher grain yields in sorghum and setaria, respectively in black soils and 66% more grain yield in sorghum in red soils over up and down cultivation (Rama Mohan Rao *et al.*, 1978). Contour cultivation at Ballari, India was more beneficial (92% increase in yield) than Farmer's practice during a drought year (Rama Mohan Rao et al., 2000b).

Rama Mohan Rao *et al.* (2000b) -Vertisols: Figures in parentheses denote percent increase or with negative sign indicates decrease in yield.

Table 4: Influence of contour cultivation and fertilizer use on yields (t ha^{-1}) of crops

Crop/cultivation practice	No NPK				Recommended NPK			
Bangalore (Alfisols)								
Finger millet								
Cultivation along slope	0.55				0.79(44)b			
Contour cultivation	0.69				1.24 (89)b			
	(25) a				(58) a (126)c			
Groundnut								
Cultivation along slope	0.57				0.87(53)b			
Contour cultivation	0.73				(55) a (137)c			
	(28)a				1.35(85)b			
Ballari (Vertisols)	**Drought years**				**Normal years**			
Winter sorghum	Slope							
	0.5	1.0	1.5	Average	0.5	1.0	1.5	Average
Up and down cultivation (control)	662	400 (–40%)	370 (–44%)	477 (––)	1191	1096 (–8%)	939 (–21%)	1075 (––)
Contour cultivation	1213 (83)	670 (68)	864 (135)	916 (92%)	1291 (8)	897 (–22)	987 (5)	1058 (–2%)

*Source: Krishnappa et al. (1994) -**Alfisols:** Figures in parentheses denote: a = % change over cultivation along the slope: b = % change over no NPK; and c = % change over cultivation along the slope and no NPK.*

Scooping

Scooping out soil to form small basins with basin listers during the second fortnight of June across the slope increases the infiltration rate and reduces soil erosion thus helping to retain rainwater on the surface that recharges the soil profile in medium to deep black soils with poor infiltration (Fig. 3). A study conducted at ICRISAT (Pathak and Laryea, 1995) revealed that the scoops reduced seasonal runoff by 69% and soil loss by 53% and increased the pearlmillet grain yield by 35% when compared to the flat land surface.

Broad-bed and Furrow System

A raised land configuration "Broad-bed and furrow" (BBF) system with an implement called "Tropicultor" developed by ICRISAT acts both as a disposal system during high-intensity rains and as a conservation measure during low rainfall situations in the same cropping season on black soils for sustaining crop yields under vagaries of monsoon varying from 500 to 1300 mm (Pathak *et al.*, 2009). The BBF system consists of a raised flatbed approximately 95 cm wide and a shallow furrow about 55 cm wide and 15 cm deep across the slope on a grade of 0.2 to 0.6% for optimum performance and once formed can be maintained for 25-30 years. This will save considerable costs as well as improve soil health and suitable for narrow-spaced row crops. Even if a few rows are lost due to the furrow, the yields are made up due to better *in-situ* rainwater conservation.

The relative performance of different bedding systems, i.e., flatbed (FB), BBF, narrow bed and furrow (NBF), and raised-sunken bed (RSB), was studied in black soils at Indore. The results indicated that the maximum maize yields (2.01 t ha^{-1} and water use efficiency of 8.81 kg ha^{-1} mm^{-1}) were observed in the BBF system followed by the RSB and FB systems. In Vertisols of Ballari, the bedding system proved effective in conserving the rainwater, increasing the soil water in the profile, and producing 24% higher winter sorghum grain yield and safflower yield was 8% higher as compared to flat sowing (Average of 8 years). The BBF with residue incorporation conserved rainwater *in-situ*, increased groundnut yields (rainy season) and rapeseed (postrainy season), and produced greater returns with a higher B:C ratio in the northeast hill (NEH) region of India (Kuotsu *et al.*, 2014).Even at Bijapur also BBF produced only 8.5% runoff as against the normal sowing (15.6% runoff) and yields with 15.2% increase in *rabi* sorghum yields.

Conservation Furrow System

The low-cost *in-situ* rainwater conservation furrow opened either during planting or during intercultural operation using a country plow at 3-5 m apart on the contour is a simple practice adopted in Alfisols and associated soils in rainfed areas of 400-900 mm rainfall with moderate slopes varying from 1 to 4. These furrows harvest the local runoff water and improve the soil moisture in the adjoining crop rows, particularly during periods of water stress and found to increase crop yields by 10-25% and it costs around Rs 1000-1500 ha^{-1}.

Contour/graded border strips

Border strips of 20-30 cm height bunds are formed at regular intervals of 10 to 40 m depending upon slope with 0.1 to 0.2% grade and are more suited on lands having < 2% slope. Generally, border strips of 60 m in length at 10 m intervals are recommended. This system is efficient in wetting the soil profile uniformly and increases crop yields by 20 to 30%. In the black soils of P.C. Pyapili watershed in Anantapur district of Andhra Pradesh layout of graded border strips conserved the rainwater, recharged the soil profile, reduced the runoff and soil loss, and increased the yields of sunflower and winter sorghum by 23 and 25%, respectively with greater yields during drought year compared to the normal year (Table 5). When border strips were supplemented with terrace level measures i.e. graded bunds, the yields of sunflower and sorghum increased further up to 38 and 42%, respectively. These results indicate the benefit of border strips in the Vertisols of the Deccan Plateau in South India (Patil *et al.,* 2004).

Compartmental bunding

Compartmental bunds of cross section 0.06 m^2 with a bottom width of 0.5 m, top width of 0.1 m, height of 0.2 m, and side slope 1:1 are formed using tractor/bullock drawn bund

Table 5: Effect of rainwater conservation practices on crop yields (kg ha^{-1}) in the watershed.

Treatment	1999–2000		2000–2001		Pooled	
	Sunflower	Sorghum	Sunflower	Sorghum	Sunflower	Sorghum
Control	626	910	474	450	550	680
Graded bund alone	702 (12%)*	1012 (11%)*	529 (12%)*	530 (18%)*	616 (12%)*	771 (13%)*
Border strips + Graded bund	888 (42%)* (26%) **	1274 (40%)* (26%)**	631 (33%)* (19%) **	655 (45%)* (24%) **	760 (38%)* (23%) **	965 (42%)* (25%) **

Source: Patil et al. 2004; Figures in parenthesis indicate % increase over control;**Figures in parenthesis indicate % increase over Graded bund alone*

former during late summer in red soils and in the rainy season (June) in Vertisols in farmers' fields. The size of compartments to be farmed in farmers' fields is 10 m × 10 m for a field slope up to 2-2.5% with a cost Rs. 3000/- per ha. Compartmental bunds are retained up to first week of September in cereals and oilseeds that are sown during 2nd fortnight of September and up to 3rd week of September for pulses that are sown during 1st week of October. Compartmental bunds provide a greater opportunity time for rainwater to infiltrate into the soil and wet the soil profile completely for early sowing of winter crops thus producing greater crop yields. In Vertisols of Bijapur, compartmental bunding conserved more rainwater and produced 23% higher winter sorghum yield over flat sowing (Patil and Sheelavantar, 2004). In Vertisols at Ballari, compartmental bunding increased sorghum yields by 17% and WUE by 13% over flatbed (Patil, 2003). Adoption of compartmental bunding in Vertisols at Vijayapura, India in *Rabi* sorghum, sunflower, safflower, and chickpea produced higher yields by 40, 35, 38, and 50%, respectively. The effect of compartmental bunding on crop productivity was greater during a drought year compared to normal rainfall situations both at Vijapura and Ballari. It also significantly controls the runoff. The Compartmental bunding produced greater net returns and B:C ratio over the farmer's practice of flat planting (Table 6). (Umarfarooque Momin, *et al.,* 2021). Adoption of compartmental bunding with recommended rate of

Table 6: Impact of compartmental bunding on various crops

Technology	Yield (kg ha^{-1})	Net returns (Rs. ha^{-1})	B:C ratio
Rabi Sorghum			
Compartmental bunding	1305	17490	2.88
Farmers' practice	932	9582	2.37
Sunflower			
Compartmental bunding	1013	18315	2.86
Farmers' practice	690	8610	2.23
Safflower			
Compartmental bunding	930	22230	3.12
Farmers' practice	734	15741	2.80
Chickpea			
Compartmental bunding	413	563	1.55
Farmers' practice	413	563	1.55

nutrients through integrated nutrient management improved the plant growth and resulted in higher crop yields varying from 25-34% in chickpea, 30-33% in sunflower and 34% in *rabi* sorghum (Fig. 4) (Anon., 2010).

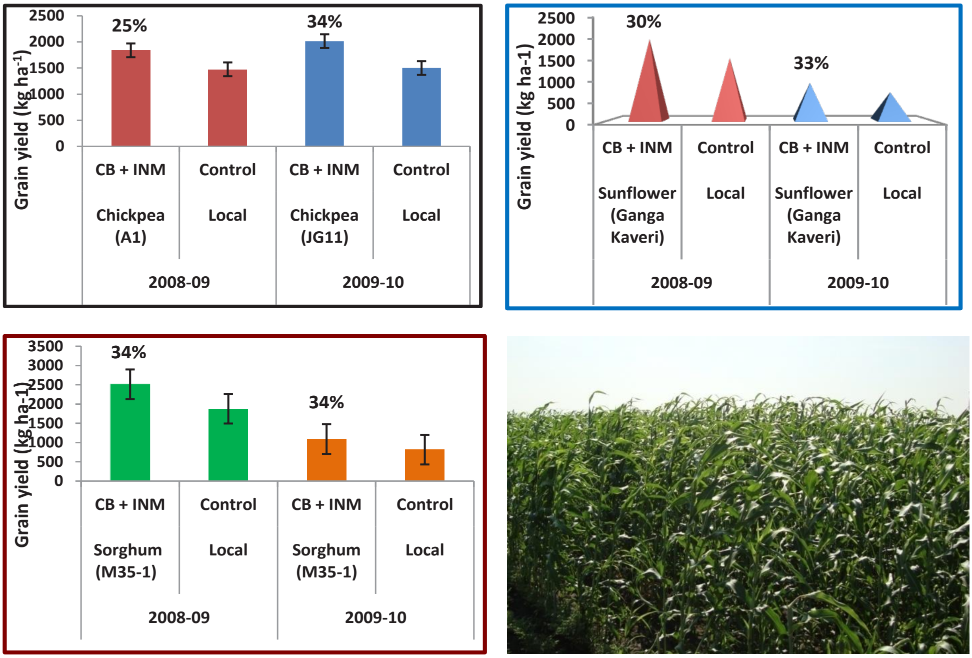


Fig. 4: Compartmental bunding with integrated nutrient management on crop yields of chickpea, sunflower and rabi sorghum in Vertisols (Farmer's fields) of Ballari and Kurnool districts.

Ridges and furrows

Cultivation of crops under ridge and furrow system across the major land slope with a gradient of 0.2 to 0.4% in land having a 1 to 3% slope will conserve more rainwater *in-situ*. This is suitable for widely spaced crops with 60 cm or more row spacing. A field length of 60 to 90 m is optimum for the cultivation of crops with ridges and furrows. In Vertisols of Ballari, ridges, and furrows were more effective in the conservation of rainwater and increased winter sorghum grain yield during a drought year (36%) compared to a normal year (16%). Sunflower seed yield also was higher by 21 and 24% and water use efficiency was greater by 11 and 21% at the Research Farm and farmers' fields, respectively (Patil *et al.,* 2013). Even ridges and furrows increased the WUE of winter sorghum by 16% over flat sowing. Similarly, at Bijapur, India, the formation of ridges and furrows in Vertisols conserved more rainwater *in–situ* and produced 26% higher winter sorghum grain yields and 25% greater water use efficiency over flat sowing (Patil and Sheelvantar, 2004). Tied ridging in the Vertisols of Bijapur was more beneficial in normal rainfall and drought years with 45% higher yields of pigeonpea whereas during the above-normal years yield increase was marginal (8%) due to water stagnation. At Bijapur, *rabi* sorghum yields increased from 15% in BBF to 17.8% (Broad Furrow and ridges), 27.7% (BBF) to 50% in ridges and furrow over farmers practice of cultivation (Average of two years) under different *in-situ* moisture conservation practices.

Zingg terracing

Zingg terracing is adopted in low to medium-rainfall areas in Vertisols with contour/ graded bunds. In Zing terrace 30% of the area on the upstream side of the bund is leveled and in this leveled area assured crop yields are realized during drought years. This is done by cutting 15 cm of soil and putting it all near the bund to make flat land for 30% of the area on the upstream side of the bunds. A lower one-third portion of the inter-bunded area is leveled to spread the runoff water in a large (receiving) area with cultivation of water-intensive crops while dry crops are cultivated in the unleveled (donor) area. In the leveled one-third portions, the normal crops can be harvested even during severe drought years and it is possible to cultivate two crops during a normal year. This will increase both cropping intensity and crop yields in the region. In Vertisols of Bijapur, Zingg terrace increased *rabi* sorghum, sunflower, greengram and pearlmillet yields by 39, 82, 113 and 139%, respectively over a period of 5 years (Table 7). The yield advantage was more visible during sub-normal years (Shiratti, *et al.,* 2022).

Table 7: Effect of Zingg terrace on crop yields (kg ha^{-1}) in Vertisols of Bijapur

Crop	**Average yield (kg/ha)**		**Yield advantage (%)**	**B:C ratio**
	Zingg terrace	**Farmers' practice**		
Rabi sorghum (5 years) 1075		773	39	1.13
Sunflower (5 years)	1220	670	82	1.45
Greengram (3 years	320	150	113	1.04
Pearl millet (3 years)	550	230	139	1.25

Mulching

Mulching is the covering the cultivated field with unused organic material, sand, pebbles and soil to prevent soil erosion and evaporation losses, facilitate infiltration, improve the water holding capacity of the soil, conserving rainwater *in-situ*. Further through organic mulching/ residue incorporation the biomass in the soil feeds the microbes, increases microbial population which help the plants to draw nitrogen and carbon from air and phosphorous and potash from soil besides improving soil micronutrient status. Application of organic surface mulch with vertical mulching at 4 m interval at sowing in Vertisols of Ballari, India, produced 31, 63 and 103% greater sorghum yields in (Rama Mohan Rao *et al.,* 1985). In Vertisols at Sholapur, crop residue incorporation increased sorghum yield from 50 to 70%.

Dust mulch

Due to the scarcity of organic materials, low-cost method of frequent intercultivation between crop rows create dust/soil mulch during crop growth. Studies at Ballari have indicated 8% more grain yield over organic mulch and 96% higher yield over control in winter sorghum with intercultivation up to 10 cm soil depth (Table 8). Both organic and soil mulches produced 63 and 20% higher sorghum grain and straw yields over control especially during below normal/scarce rainfall situations in black soil region during postrainy season for the crops cultivated on residual soil water (Rama Mohan Rao *et al.*, 1985).

Table 8: Winter sorghum yields as influenced by dust and surface mulches

Treatment	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Control	0.93	2.43
Organic mulch	1.76	2.95
Intercultivation up to 5 cm depth	1.24	2.95
Intercultivation up to 10 cm depth	1.83	2.95
Intercultivation up to 15 cm depth	1.51	2.78

Source: Rama Mohan Rao et al. (1985)

Sand mulching

Sand mulching (2 to 10 cm) conserves top fertile soil and rainwater *in-situ*, reduces wind, water erosion and evaporation in turn increases the water availability in the profile at different stages of crop growth (Hagman, 1984). Sand mulching has been practiced by the farmers in pockets of northern Karnataka and Andhra Pradesh. Experiments conducted with sand mulching at Dryland Centre, Bijapur and MRS, Dharwad (Karnataka State) indicated60 to 70% increase sorghum, chickpea, and cotton yields (Anon., 2000 and Sudha, 1999). In Koppal, Gadag and Bagalkot districts of Karnataka with low annual rainfall (around 600 mm) and its bi-modal distribution, sand mulching increased the cropping intensity to 200% during drought years with cultivation of short duration greengram crop during *kharif*.

Plastic mulching

Plastic mulching (black LLDPE of 20 micron) created more favorable conditions for plant growth, development and increased cotton lint yield by 54% over control at TNAU, Coimbatore. Of late biodegradable plastic mulches such as Bio Telo (Dubois Agrinovations) and Eco-One (Heartnut Groves) are being used.

Soil Management

Crop residue management

Fertilizer application can be reduced by returning approximately 1.5 Pg (world) of carbon (C) stored in the crop residues produced into the soil which adds OM. A total of nearly 600 Mt of crop residues are generated every year in India from different crops. At Bangalore, incorporation of maize residue at 4 t ha^{-1} continuously for three years increased soil moisture content at sowing by 26 and 5% in 0–15 and 15–30 cm depths and in ragi yield increased by 76% compared to the plots without residue. Paddy husk application at 5 t ha^{-1} increased soil moisture, infiltration rate and grain yields of sorghum (1st year), castor (2nd year) sorghum (3rd year) by 33, 23 and 14%, respectively (Singa Rao, 2004). In Vertisols of Ballari, *Dolichos* incorporation at harvest (grain purpose)/45 DAS (mulch purpose) in the Sorghum + *Dolichos* system reduced runoff, soil loss and increased the soil water in the profile. Soil properties i.e. mean weight diameter, organic carbon and nutrient availability (N, P and K) were higher with

Dolichos incorporation when cultivated with sorghum as compared to sorghum cultivation alone (Table 9). Sorghum grain equivalent was significantly higher (3248) when sorghum cultivated with *Dolichos* for grain purpose compared to the rest of the treatments. Four years experiment results indicated that cultivation of *Dolichos* with sorghum for seed purpose and incorporation of *Dolichos* residues at harvest sustained productivity with greater net returns (Nalatwadmath *et al.* 2006).

Table 9: Runoff, soil loss, soil properties and sorghum and *Dolichos* yields as influenced by crop residue incorporation

Treatments	Av. of 4 years		MWD (Microns)	Organic C (g kg^{-1})	Available nutrients 0-15 cm (kg ha^{-1})			Grain yield (kg ha^{-1})	Straw yield (t ha^{-1})	Sorghum grain equivalent
	Runoff (mm)	Soil loss (kg ha^{-1})			N	P	K			
T_1-Sorghum without disturbance (Control)	142	4940	582	3.7	165	12	427	1469	2.64	1807
T_2-Sorghum + Dolichos (Dolichos cultivated for grain and residue incorporation at harvest)	127	3934	688	3.9	199	16	448	167+ 495	3.01	4248
T_3-Sorghum + Dolichos (Dolichos cultivation and residue used as mulch at 45 DAS)	129	4339	685	3.8	198	15	442	2121	3.27	2535
T_4-Sorghum + Dolichos (Dolichos incorporated into the soil at 45 DAS)	122	3751	696	4.0	202	16	483	2301	3.61	2756
T_5-Sorghum with inter cultivation (Twice soil disturbance)	132	4491	589	3.6	183	13	499	1916	3.05	2303
LSD (P=0.05)	--	--	35	0.03	26	NS	NS	--	--	397

Source: Nalatwadmath et al. (2006); DAS=Days after sowing

Brown manuring

Brown manure cropping is growing a grain legume with minimal application of fertilizers and chemicals and higher dry matter production with efficient weed control, increase soil N and conserve soil moisture. The grain legume crop is sprayed with a knock down herbicide before seed set, to kill both the crop and weeds. In rice cultivation, at 50 days *Sesbania* is sprayed 2,4-D ethyl easter and becomes brown after killing and it is incorporated to reduced sodicity and improve the soil fertility especially the N in irrigated area.

Application of soil amendments for enhancing soil resilience

Gypsum application

Soil amendment like Gypsum is added to the soil to improve its physical properties, such as water retention, permeability, water infiltration, drainage, aeration, structure and to provide a better environment for plant roots and crop growth. Studies indicated through gypsum application reduces Exchangeable Sodium Percentage >7.0 to < 7 (Anon., 1981).

Tank silt application

Desiltation of tank silt rejuvenate the tanks, improves the tank water holding capacity and recharges the groundwater. Application of tank silt to croplands improves soil properties, reduces the fertilizer application, meets the water and nutrients of the rainfed crops in a cost-effective manner. Tank silt improves crop yields and brings dynamic changes in the land use pattern in the region (CRIDA, 2006; Dhan, 2004 and Osman *et al.* 2001 and 2007). Tank silt application to cotton increased the benefit-cost ratio (BCR) from 1.43 to 1.86 and in chillies the BCR was higher by 11% (2.54) over control (2.28). In a study at ICRISAT, Padmaja *et al.* (2003) have registered 1.17 as average benefit-cost ratio indicating that desilting operations are economically viable and have additional benefits like environmental protection, increased soil microbial bio-diversity, improved soil quality and increased water storage leading to self-sustained land use planning. In Telangana and Andhra Pradesh nearly 40% of the total cultivated area is light textured red sandy loam to loamy sand with low clay content (<15%) and low water holding capacity (5 to 10 cm m^{-1} depth) and is a major constraint in crop production in the 80% rainfed soils. Application of available tank silt or heavy textured soil in the top 50 cm depth decreased bulk density and increased soil water content from 6.5 to 23.5%. The improved soil water and nutrient status with application of tank silt/clay increased the tomato and lady's finger yields by 10.8 and 10.5%, respectively in the Ranga Reddy District of Andhra Pradesh (Singa Rao, 2004).

Runoff Harvesting and Recyclin G

In the SAT of south India, nearly 10% to 40% of rainfall goes as runoff from the farmers' fields depending upon the land slope. Of this runoff, nearly 10% can be harvested and recycled as protective irrigation especially during subnormal rainfall/drought years through farm ponds.

Farm Ponds

Dug out farm ponds size varies with rainfall ranging from 200 to 3000^3. Considering an annual rainfall of <1000 mm, a farm pond of 250 m^3 capacity with 6 m × 6 m bottom width, 12 m × 12 m top width, 3 m depth and lined either with soil: cement (8:1) is ideal per hectare catchment area. The stored water in the farm pond is used for multiple purposes, viz., protective irrigation, fish rearing, Azolla cultivation, nourishing horticultural plants, spraying plant protection chemicals, drinking water to livestock etc. Recycling farm pond water in the SAT region of south India reduces moisture stress especially in winter sorghum at boot leaf stage or appearance of crack and in chickpea at pod development stage stabilizes crop yields especially during drought years.

Supplemental irrigation

Runoff collected in the farm pond is applied to the crops by adopting any of these methods (check basin, border strips, furrow, sub-surface, sprinkler and drip) as convenient to the farmer and the facilities available with him based on his socio-economic conditions.

Border strips

In India, the surface method of irrigation covers more than 95% of irrigated area. The excess runoff conserved in farm pond when used as supplemental irrigation at critical stages of crop growth increased the yields of beedi tobacco by 17% at Varanasi, 198% in wheat at Chandigarh. Similarly, in medium deep black soils of Bijapur, the average responses over a period of 4-5 years indicated yield increase varying from 33 to 92% with one life saving irrigation. The increase in winter sorghum yields during drought year was 157% with application of 11.8 cm irrigation at boot leaf stage whereas during severe drought year yield increased by 219% with 6.5 cm irrigation at knee height stage (Radder *et al.,* 1995). The response to irrigation was only l2% (2190 to 2450 kg ha^{-1}) with 5 cm irrigation at grain filling stage during normal rainfall situation. The runoff when received in the months of May and June is utilized for a short duration greengram by providing supplemental irrigation from harvested water (Adhikari *et al.,* 2000). The supplemental irrigation during water stress brought about 49% to 86% increases in yields in groundnut and sorghum in Chinnatekur watershed, whereas, in winter sorghum yield increased by 34% at Joladarasi watershed in black soils (Rama Mohan Rao *et al.,* 2000a) (Table 10).

Table 10: Impact of drought management techniques on grain yields of crops (kg ha^{-1})

Technique	Crops	Chinnatekur			Joladarasi		
		Without	With	% increase	Without	With	% increase
Supplemental irrigation							
	Sorghum	570	1060	86	1460	1950	34
	Groundnut	610	910	49	--	--	--

Sprinkler and drip irrigations

At Bijapur drip irrigation using pond water saved more than 50% of water compared to modified sprinkler and surface methods of application. Yield resources were also higher with drip irrigation (Table 11). Even at Solapur, sprinkler irrigation increased grain yield of *rabi* sorghum compared to contour furrow irrigation.

Table 11: Response of fruit crops to different irrigation systems in Vertisols at Bijapur

Method of irrigation	Yield increase over control (%)		
	Ber	Fig	Pomegranate
Drip	252	228	133
Modified sprinkler (Jet method)	189	128	52
Surface irrigation	149	82	60

Recommended Moisture Conservation Measures

The research results at both the Research Stations and in the farmer's fields indicate that the rainwater conservation practices reduced runoff, soil and nutrient losses and recharged the soil profile both during rainy and postrainy season and increased the yields of different crops especially during drought years. An inter comparison of the effects of various land management systems on reduction of runoff and increase in yield in Alfisols of Hyderabad is furnished in Table 12. Further the suitable *in-situ* moisture conservation practices for different crops under different soil types at dryland Centre's in India are mentioned in **table 13.** Recommended soil and moisture conservation measures for different rainfall zones in India are summarized in Table 14.

a = Effect after 4 years of continuous application; b = average of 4 years; c = porous

Table 12: Effect of land management on runoff and crop yields in Alfisols and CRIDA

Land management	Runoff reduction	Crops	Yield increase (%)
Deep tillage	46	Sorghum	31
	34*	Sorghum	28
Scoops (40 mm)	69	Sorghum	28
Tied ridges	39	Sorghum	35
FYM at 15 t ha^{-1}	51	Maize	56
Straw mulch[a] (15 t ha^{-1})	76	Maize	53
Contour bunds[b]	37	Maize	36
Graded bunds[b]	31	Maize	NA
Porous barrier[c]	66	Maize	NA
Sand mulchd (95%)	80	-	-

Source: Rao et al. (1994).

Table 13: Recommended/demonstrated *in-situ* rainwater conservation measures in the farmers' fields at different Dryland Centres/locations

Location	Crop	Suitable inter-terrace land treatments
Bijapur	Safflower Chickpea Winter sorghum	Compartmental bunding Compartmental bunding; Ridges and furrows Tied ridging
Akola	Pigeonpea	Opening furrow at 30 DAS after every two rows
Bellary	Winter sorghum Chickpea Safflower	Compartmental bunding; Ridges and furrows Compartmental bunding Bedding system
Kovilpatti	Winter sorghum	Compartmental bunding
Sholapur	Chickpea	Compartmental bunding
Bangalore	Pigeonpea	Ridges and furrows; Furrow at 3 m interval
Anantapur	Groundnut	Contour cultivation; Dead furrow at 3 m interval

Table 14: Recommended soil and moisture conservation measures for different rainfall zones in India

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

Source: Vittal et al. (2003); Somasundaram et al. (2014); Patil (2013); Patil et al. (2013)

barriers are 3 years old; d = average of 2 years after bringing the sand content of the surface to 95%.

*Data from CRIDA; other data from ICRISAT. Tillage results are presented as % increase over traditional practice. Data on FYM and straw are presented as % increase over an unamended control.

Applications of Nanotechnology, Hydrophobic and Polymers in Rainwater Conservation

In the recent past, nanotechnology has garnered significant scientific gusto because of its extensive utility across industries and including the agricultural sector. The emerging nano fertilizers and insecticides showing promise as agents for enhancing plant growth and protection. Among those, nano fertilizers (NFs) can substitute 25% chemical fertilizers and reduce the negative consequences of fertilizers.

Nanotechnology for increasing soil water retention

Wong and Karn (2012) reported that different companies are starting to produce new nanomaterials to mitigate global problems such as the scarcity of water for irrigation. A nano-sand water repellent was developed to prevent water drainage in drylands and support the release of nutrients and molecules to support plant growth (Davidson and Gu, 2012).

The treated sand can stop water drainage below the depth of the plant roots and maintains a subsurface water table, providing vegetation with a constant water supply. Other nano materials are nanomembranes for water purification and desalination that would be several times more energy efficient. Nano clay is made up of clay minerals divided into their smallest components that are 0.7-1.5 nm thick, with a diameter of 20-300 nm and mixes with water. Nano clay works as a binder and keeps moisture in the sand and thus it creates constant growth conditions for plants to survive under dry conditions (Mura *et al.,* 2013). Padidar *et al.* (2015), found that the application of nano clay at a concentration of 2000 ppm resulted in a reduction in soil erosion due to wind.

Application of zeolites and synthesized nanomaterials for efficient soil water use.

Zeolites are naturally occurring aluminosilicates that exhibit alkaline hydration and contain a wide range of practical applications, such as their utilization as soil-binding agents and nutritional supplements. Several examples of mineral zeolites include analcime, chabazite, clinoptilolite, heulandite, natrolite, phillipsite, and others. Zeolites absorb and slowly release water, can be used as a soil amendment to improve water retention in sandy and low-clay soils and to improve porosity of impermeable soils. They could be used to conserve water in the root zone in conjunction with traditional techniques, such as mulch farming and application of manure (Bhattacharyya *et al.,* 2006; Pal *et al.,* 2006; Oren and Kaya, 2006). When pretreated with nutrients, zeolites can be used as an agent for the slow release of nitrogen and phosphorus. They can also be used to enhance the availability of micronutrients, such as zinc (Oren and Kaya, 2006). Alternatively, zeolites can be used in soil remediation to absorb metal cations and reduce local concentrations of toxic substances that inhibit plant growth and nitrogen-fixing soil microbes (Pisarovic *et al.,* 2003). The potential diversity and multiple uses of zeolites make them ripe for further research and development. Advances in nanotechnology suggest that it is possible to engineer zeolites further to increase the efficiency of fertilizer by developing slow-release delivery molecules that decrease losses to water and air and increase uptake by plants (NRC, 2008). The dry-Vertisols when rapidly exposed to water, they release a large amount of heat at the soil surface, which causes slaking of soil aggregates that reduces the ability of water to percolate downward and results in water runoff. Although no current method addresses this problem, it is conceivable that materials could be developed to interrupt the process by improving the biophysical stability of soil aggregates and dissipating the heat emitted during wetting. According to Inglezakis *et al.* (2012), it has been determined that the zeolites application leads to improvements in infiltration rate, saturated hydraulic conductivity, cation exchange capacity, and the reduction of water losses caused by deep percolation.

Conclusion

In-situ and *ex-situ* rainwater conservation practices have great potential to conserve rainwater and supplement moisture to the crops especially during droughts. Thus, based on definite climatic events and rainfall regime, rainwater management interventions are needs to be prioritized. Certainty of climate change and predicted increase in high intensity rainfall events with reduced number of rainy days demands largescale adoption *in-situ* rainwater conservation measures at Farm levels. Simultaneously, it also calls for continuous efforts from all stakeholders from policymakers to the farmers to work together to design programs/ schemes with proper credit allocation and execution through participatory approach. Regional specific, prioritized rainwater harvesting techniques needs to be popularized and adopted at farm level by converging government programs to cope with extreme climatic events for sustainable crop productivity and ensure water for all farm enterprises. The Government schemes like MNREGA may be further strengthened to build awareness and to construct rainwater conservation structures in rural areas to cope with acute drought situation especially in arid and semiarid regions of India. To enhance conserved rainwater use efficiency adoption of improved irrigation techniques such as alternate furrow, sprinkler, drip irrigations is essential in tandem with crop diversification towards low water consuming crops and cultivars. Research in nanotechnology particularly of (i) engineered nano-products (NPs) for soils moisture retention and release, (ii) development of nano-magnets for soil contaminant retrieval, (iii) development of nano-membranes for water treatment/ purification, (iv) fertilization and herbicide application through NPs, (v) synthesis of nano fertilizers for soil and plant application, and (vi) development of nano-sensors to monitor soil quality are essential to enhance potential of climate reliance in agriculture.

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Management of Water Resources through Land Use Planning along the Coastal Central Western India

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Introduction

The states of Gujarat, Maharashtra and Goa cover the parts of landmass along the coastal central western India, the area which leads the financial dynamics of the whole country. The western coastal plains touch Arabian sea, the gate way of business and travel across high seas since time immemorial. The belt is not only heavily industrialized but also possesses fertile plain lands that feeds the geometrically growing population of coastal cities. Total coast line of India is 7516.6 km long, of which 6100 km is in mainland and rest is of Andaman, Nicobar, and the Lakshadweep islands. Gujarat having longest coastline of 1600 km, that covers coastal districts like Kachchh, Jamnagar, Porbandar, Junagadh, Amreli, Bhavnagar, Anand, Ahmedabad, Vadodara, Bharuch, Surat, Navsari, and Valsad. The Maharashtra covers 652.6 km coast with the districts of Thane, Raigadh, Ratnagiri and Sindhudurg. This coastal belt encompasses some of the highest densely populated area with an average population density of 80 individuals per sq. km. This stretch of land from Ahmedabad to Mumbai is also considered as the golden corridor of India because of industrialization, business, fertile and crop diversity. Apart from population and industrial growth, the developmental activities in the form of roads, rail and related infrastructure facilities also occupy huge chunk of land mass as well as affecting the surface water hydrology of the region. World over, it is observed that there is competing demand for natural resources like soil and water for Agriculture, Horticulture, Forestry, Aquaculture, Urban, rural cities and towns, Industry, Recreation and road, rail infrastructure. Scientifically sustainable Land Use Plan generally takes the back seat due to monetary benefits involved and influential lobbies behind the type of land use, which ultimately results in natural disasters that too with increasing frequencies and growing numbers of incurable diseases.

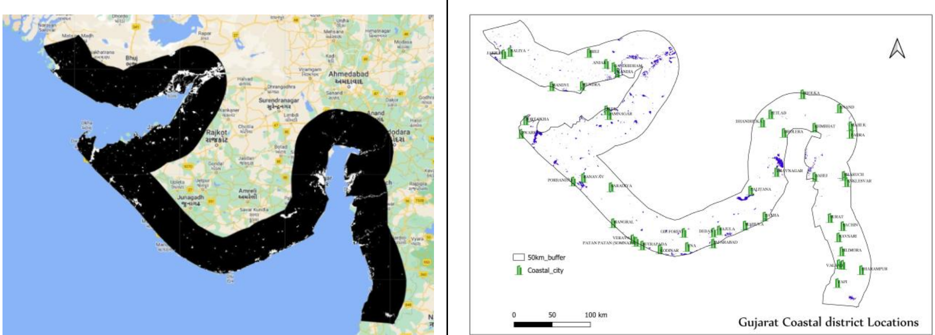
The major rivers draining into Arabian sea are Sabarmati, Mahi, Narmada, and Tapti. The region also has good canal network from the dams like Sardar Sarovar, Ukai Kakrapar, Daman Ganga, etc which supply good quality canal water grown in the command area of these dams. However, the crux of the matter is, initially the dams were made to supply water for crops, to increase crop productivity, cropping intensity, but, with time due to population pressure, the canal water is now supplied to meet the demands of human needs and industries. In areas where canal water is not available, irrigation is done by using groundwater. With canal irrigation, the cropping patterns has shifted to cash crops or the crops giving high returns. The major water consuming crops occupying vast areas of culturable command area, CCA, are sugarcane, banana, paddy, water lily and vegetable crops (Anonymous 2015). Therefore, ground water exploitation in most parts of the region is commonly observed which is not only accelerating sea water intrusion in the coastal strip but also affecting the desirable water quality standards required for human, animal, and crop use. Effluent from industries is generally discharged in rivers and streams joining the Arabian sea, pollutants are affecting the aquatic life along the coast. Due to which necessary vegetative cover that protects land from the tidal waves is getting sparser. The aquatic biodiversity could be easily seen through satellites imageries of the past and present that give the unbiased picture of changes.

Coastal Erosion

With loss of vegetative cover, barren stretches of land are getting washed away due to coastal erosion, resulting in migration from coastal villages to cities, creating issues of domestic water demands in cities, vicious circle continues. As per the recent articles in The Times of India, India lost one third of its coastline due to erosion, of which Gujarat, Diu and Daman has seen erosion of 26%, Maharashtra 24% and Goa 12%. In studies conducted around Navsari coast, it was found that approximately 60.81 sq km of land had been eroded. Although, coastline changes are gradual natural process, but with increasing anthropogenic activities and climate change, such processes have quickened, which directly affects the survival and livelihood of coastal villagers. In last 50years, Arabian sea has marched into almost 1.5 to 2.0 kms inside the earlier coast line.Rajawat *et.al.* (2014) in the assessment of satellite imageries reports 45.5% of total coastal length to be under coastal erosion.

Seawater Intrusion

Seawater intrusion (SEI) is intensified and aggravated due to over exploitation of groundwater, sea level rise and climate change. According to Ghyben- Herzberg principle,



Central Western Coast of India

the stability between fresh water and salt water is caused by the density difference between the two, until the pressure equalizes. Siddha and Sahu (2020), Ahmed A.T., Askari B (2016). The degree of SWI is also associated with the climate change effects like increase in sea level and rise of temperature and reduction of precipitation. A review study by Siddha and Sahu (2020) mainly reports the status and vulnerability of SWI with the aquifers of coastal region of Gujarat. The study also delivers some advanced management strategies such as dilution of saline water by artificial recharge techniques, construction of physical barriers in the subsurface to reduce intrusion.In a study conducted in Thane district of Maharashtra, it is reported that back water from sea through the rivers is influencing SWI (Omprakash and Gadkari (2018), Keesari, *et.al.* (2014).

Pandit and Fulekar (2017) did quality characterization of coastal water in Gujarat coast using principal component analysis method during pre-monsoon time. The findings indicated that most of the nutrients and chemical parameters are influenced by the increase in salinity and anthropogenic activities.

Approaches to deal issues of Water in Coastal Region

- Appropriate Land Use Plan and it's on ground execution
- Selection of Crop
- Water Management
    - o Irrigation
        - – Right Irrigation Methods
        - – Irrigation Scheduling
        - – Mulching techniques
    - o Drainage
    - o Rain Water Conservation in big / small water bodies along the coast.
    - o Protection
- Afforestation along the coast
- Policy decisions

Land Use

Land use land cover (LULC) data play a central role in climate change assessment (Peter *et al.*, 2011). Remote sensing technology and geographic information system (GIS) provide efficient methods for analysis of land use issues and tools for land use planning and modelling. By understanding the driving forces of land use development in the past, managing the current situation with modern GIS tools, and modelling the future, one can develop plans for multiple uses of natural resources and nature conservation. To understand how LULC change affects and interact with global earth systems, information is needed on what changes occur, where and when they occur, the rate at which they occur, and the social and physical forces that drive those changes. The information needs for such a synthesis are diverse. Remote sensing has an important contribution for making and documenting the actual change in land use/land cover in regional and global scales.

Remote sensing data is the most common source for detection, quantification, and mapping of LULC patterns due to its repetitive data acquisition, suitable for processing, and accurate geo-referencing. Quantification of such changes is possible through GIS techniques even if the resultant spatial datasets are of different scales/ resolutions (Nayak *et. al.*, 2017). Lakkad and Shrivastava (2022) used Remote Sensing and GIS techniques to estimate sediment yield and sediment delivery ratio for Dhaman Khadi Sub Watershed in Western India. They prioritized the micro watersheds for planning, execution, and management and to produce erosion susceptibility maps using ArcGIS interface and ArcSWAT model. The average erosivity for the period of 30 yrs for average rainfall of 1106mm was estimated to be 480.63 mt ha/cm, they also derived erosion susceptibility maps under 6 different classes for prioritization of conservation programmes. Bhanderi, *et.al.* (2020) assessed the changes taking place in the land use pattern of nine micro watersheds near Dandi, located on the Arabian Sea coast, near Navsari city, using Remote Sensing and GIS facility and ground truthing from the selected micro watersheds. They characterized, identifying major problems, and prioritized with emphasis on ground water recharge to combat seas water intrusion, later, gave specific solutions to cope with the problems. The prioritization of micro watersheds could help the government to put investments in the order of importance of micro watershed for the sustainable welfare of coastal communities. Nayak *et al.*, 2022 reports decrease in agricultural and forest areas, and increase in orchards and other vegetations, in most of the districts of South Gujarat, during 2000-2011. There is shift in forest area to Orchards and other vegetation, in Surat (18.25%) district there is major shift, could be due to avenue plantations, orchards and development of gardens. Forest area had decreased in almost all districts except in Bharuch. Barren land has increased in most of the districts which could be due to development of salinity and alkalinity levels along the sea coast, mining and increase of waste dumping sites and conversion of forest land into degraded forest lands. Built up areas has shown significant increase in the region confirming construction of new residential societies, road network, industry in the region, rising population, in the districts of South Gujarat. Almost all evaluation studies done through remote sensing and GIS software's, on land use changes indicate fast changing land use dynamics resulting in warming and climate change.

Land Use Planning

Land Use Planning is mostly governed by commercial benefits rather than suitability or capability of the land unit. The growing population not only needs food, nutritional and financial security but also environmental security for sustainable use of land and water. Indiscriminate and unplanned use of natural resources are already showing up in the form of natural disasters at increasing frequencies, with time. The pollution levels of rivers joining the oceans have crossed the acceptable limits for human and animal consumption. Polluted water when used for irrigation is transferring pollutants – heavy metals in crops, entering in the food cycle of human and cattle. To cope these issues effective monitoring, planning of land use and strict implementation is the need of the hour.

Scientific planning of use of land is the pre requisite to high sustained outputs. The FAO Guidelines for Land-use Planning (FAO, 1993) defined land-use planning as:

Land-use planning is the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land-use options. Its purpose is to select and put into practice those land uses that will best meet the needs of the people while safeguarding resources for the future. The driving force in planning is the need for change, the need for improved management or the need for a quite different pattern of land use dictated by changing circumstances.

Land-use (or Land Resources) Planning is a systematic and iterative procedure carried out in order to create an enabling environment for sustainable development of land resources which meets people's needs and demands. It assesses the physical, socio-economic, institutional, and legal potentials and constraints with respect to an optimal and sustainable use of land resources, and empowers people to make decisions about how to allocate those resources. Watershed and the land use are quite inter-dependent. Watersheds with a healthy aquatic system -in the form of adequate streams & wetlands, and an equally healthy biotic system -in the form of adequate flora and fauna, are generally sustainable systems. Watershed management is the process of formulation and carrying out a course of action involving the manipulation of natural, agricultural, and human resources in a watershed to provide goods and services that are desired by and suitable to the society, but under the condition that soil and water resources are not adversely affected. Watershed management must consider the social, economic and institution factors operating within and outside the watershed (Food and Agricultural Organization, FAO, cf. Gregersenk et al., 1987). This is an integrated approach for production and utilization of natural resources.

Watershed Management

Water management could also be achieved through selecting suitable farming activity commensurate with water availability that could meet the watering demand. It could also be selection of multiple crops in the same filed in various seasons as per the demand and supply of water. Such farming system will not only help in optimizing water resource but will also act as a cushion in case of failure of one crop. Mixed farming includes horticulture, forestry, floriculture, dairy farming, sweet water as well as saline water aquaculture, apiculture, goatry, etc. Area allocation to any of these types of farming could be the deciding factor as per the land use capability and water availability. Manivannan and Thilagam (2022) summarizes that to achieve sustainable agriculture development in coastal watersheds, in situ moisture conservation by contour trenching, vegetative barriers in hilly tracts, while using surface water harvesting techniques like wells, sunken pond, artificial percolation ponds, recycling, lining of ponds and providing protective irrigation needs to be adopted. Manivannan *et al.* 2022 states that blue print of irrigation and water conservation structures needs to deliberated, as due to climate change and melting of glaciers there could be increase in river and the trend will reverse in the long term, high intensity rainfall events and temperature will have its own consequences. The peak discharge rate will be high resulting in frequent floods, hence necessary designs need to be adopted for protecting structures in addition to afforestation for conservation of soil and water.

Rain Water Harvesting in Lakes and pond

In the findings of several research studies at Navsari Agricultural University, farm ponds are recommended for conservation of rain water during monsoon and subsequent use for various purposes during the year. Farm ponds constructed in the natural depression of a farm land or village is a good option to conserve good quality rain water. The pond not only store water for supplemental irrigation during *kharif* and *rabi* crops but also give fish harvest and acts as a sump to drain water from the fields in areas having high water table. In coastal areas having high water table, series of such ponds act a check against sea water ingress through sub surface flows. Also, these low points having waterlogged conditions in a watershed should be converted into scientifically designed ponds to raise sweet water fish, ducks, and other recreational activities. Shrivastava, *et. al.* 2012 and Shrivastava, *et. al.* 2015. reports improvement in ground water quality in wells by construction of ponds to conserve rain water and the benefits derived from such water bodies in a micro watershed. Farmers of the South Gujarat coastal region are recommended to harvest as much rain water as possible to maintain ground water quality below (EC=2 dS/m) as per catchment area as tabulated below. The suggested modes of harvesting in decreasing order of preference could be Pond, Check dam, Percolation pit, Percolation well, Trenches and Sub soiling, as per availability of land, catchment area, water demands, financial capacity, topography, rainfall pattern, soil type, vegetative cover and nearness to sea, Shrivastava, *et. al.* 2015

S.No.	Area (ha)	Mode of Harvesting
1	> 2	Pond & Check Dam
2	2 to 1	Percolation pit
3	1 to 2	Percolation well
4	< 0.5	Trenches & Sub soiling

Wetlands

Wetlands are regions where water plays a major role in regulating the surrounding ecosystem, along with the plant and animal life that it supports. They ae the biggest source of ground water recharge in addition to sustaining the ecology of the region. They usually develop where the water table is close to the land surface or where the land is submerged in water. They are characterized as "lands bridging terrestrial and aquatic eco-systems when the water table is typically at or near the surface or the land are covered by shallow water. On February 1st, 1982, India ratified the Ramsar convention to preserve and prevent Ramsar Sites. The Wetlands Rules 2017 permit notification of all wetlands, regardless of their location, size, ownership, biodiversity, or ecosystem services values, with the exception of river channels, paddy fields, man-made water bodies specifically built for drinking water, aquaculture, salt production, recreation, irrigation, and wetlands located in areas covered by the Indian Forest Act of 1927, the Forest (Conservation) Act of 1980, the Wildlife (Protection) Act of 1972, and the Coastal Regulation Zone 2011. Over 7 lakh wetlands, or 4.5% of the country's geographical area, exist in India, yet none of them have been recognized in accordance with domestic laws. The Wetlands (Conservation and Management) Rules, 2017, set forth regulations for wetlands. In India, there are 75 Ramsar Sites as of August 2022. The Ramsar sites are kept up-to-date in Montreux Record to monitor any significant ecological changes that could have a positive or negative impact on any of the wetland sites. As of now there is no specific legal framework for wetland conservation, management and their use in India. Currently, wetlands come under the Environment (Protection) Act, 1986 and other various legal instruments, related to environment and forests.

Coastal wetlands, including mangroves, estuaries and coral reefs, are key habitats for marine life and often function as natural barriers against saltwater intrusion, protecting coastal land and inland water habitats. India harbours a substantial area of the global wetlands. India has about 1,50,174 sq. km (6.9% of the total geographical area) of wetlands, with the highest share of Gujarat. In Gujarat, the coastal and inland wetlands cover 35.8% and 6.0% of the total wetland area respectively.About 1/4th of fascinating wetlands are in Gujarat The two gulfs - Kachchh and Khambhat and the two Ranns - Great and Little, cover a vast area of coastal wetlands and mixed sea and freshwater wetlands, making this part of the land incomparable in the country.

Rao and Balasubramanian (2021) Segregating the ecosystem services indicate that the annual value of indirect ecosystem services (sediment retention and eco-tourism) is usually thrice the estimates of direct provisioning services. The multiple benefits (both direct and indirect) provided by the Kuttanad wetlands to the different stakeholders implies the relevance of wetlands and hence highlights the necessity of conservation and management of Kuttanad wetlands for sustainable use in the future.

Percolation pit for clay soils of South Gujarat

To harvest rain water and to maintain their water quality, farmers of coastal area of south Gujarat are recommended to construct a percolation pit near their bore well, in the available natural depression / monsoon drain. The size of pit could be 4.0 m long x 3.0 m wide x 2.0 m deep, along with 200 mm PVC strainer pipes up till 12 m depth inserted before digging the pit. It could help in marginally improving the water quality or prevent further deterioration in water quality. The pipe should be compulsorily capped at the top and should be about 0.6 m above ground to avoid direct entry of runoff or any rodent in the well, (Shrivastava, 2010).

Organic Carbon for Water Conservation

Soil carbon plays an important role in increasing soil fertility and improves water holding capacity of soil as well. In other words, improves water storage efficiency and ultimately increasing crop water use efficiency. Rawls *et.al.* (2003) found that at low organic carbon contents, the sensitivity of the water retention to changes in organic matter content was highest in sandy soils. Increase in organic matter content led to increase of water retention in sandy soils, and to a decrease in fine-textured soils. At high organic carbon values, all soils showed an increase in water retention. They observed the largest increase was in sandy and silty soils. Results were expressed as equations that can be used to evaluate effect of the carbon sequestration and management practices on soil hydraulic properties.

The carbon sources help in regulating amount of greenhouse gases including water vapor, carbon di oxide, methane, nitrous oxide, ozone, and some artificial chemicals such as chlorofluorocarbons (CFC). The right amount of greenhouse gases in earth surface keeps it warm enough to all forms of life to exist. If greenhouse gas falls below then the earth's temperature will be too low to support flora and fauna, whereas, more concentration will make it warm to support all life forms. The key is balance between source and sink in the carbon cycle. The most important sinks are oceans, forests, and soil on land. The forests and oceans each remove around one fourth of the carbon than humans add to the atmosphere. During the last one and half century, the increased human activities particularly burning of fossil fuels, agriculture and deforestation are increasing the concentration of greenhouse gases. This enhanced greenhouse effect is contributing to warming of earth that is causing climate change.

Afforestation

Forests could play an important role to mitigate the impacts of climate change. Forests are reservoir, sink and source of carbon, as it sequesters more carbon than any other terrestrial ecosystem. The diversity of forests in India makes it resilient to climate change and also an efficient sink of carbon. Vegetative cover all along the coast also help in recharging groundwater, along with sustaining the air and water quality. In India forest cover and Tree Outside Forest (TOF) is assessed periodically in unbiased way using remotely sensed satellite imageries and findings are published in "India State Forest Report (ISFR)". Forests play a major role in water cycle by regulating evaporation, runoff, infiltration, recharge of water along with several other benefits. Layers of forest canopy, branches and roots can store and release water vapor, which controls rainfall. Forests can also help reduce the impacts of flood from storms by blocking and slowing down the flow of runoff. In Gujarat, out of total geographical area of 19602 thousand hectares, forests are in 1834 thousand hectares, which is 9.62% of the total area. Chris Fowler and David Pedley (2013) report that in some catchments, there is clear evidence that plantation forestry can have an impact on water yield by intercepting rainfall and preventing it from entering rivers and streams. Given the increasing pressure on water supply for a range of uses and values, this is likely to result in further consideration of this issue in various regions throughout New Zealand. When considering potential regulation of new plantings, it is important that afforestation effects on water yield are not viewed in isolation. Any proposed regulation should also consider the benefits of plantation forestry, the economic and environmental consequences of the proposed regulation, and the availability of other alternatives to achieve the desired objective.

Miyawaki Forests

Miyawaki technique developed by Japanese botanist Akira Miyawaki, in late 1970's, to grow dense forests of native plants is adopted all over the world, in India there are already hundreds of thousands of such forests across many cities. The natural forests that take more than 100 yrs to grow, is established in 2 to 3 yrs, after which it does not require much of maintenance and in 20 to 30 yrs it resembles natural forests. It is reported to be 30 times denser and develops 10 times quicker. Plant saplings of different native species are planted in layers, at approx. 60 cm spacing, according to their height, e.g. Up to 3m, 4m, 8m and above. Bamboo sticks are used to train them for vertical growth, the plants are watered and fertilized initially for quicker growth. In the densely populated coastal cities having residential, industrial and other infrastructural load, Miyawaki technique of growing forests in barren lands along the coastal cities could not only help in providing clean air, recharging ground water, and improving the micro climate of cities, but also act as a barrier against tsunami threats. It will also help in fulfilling the Indian pledged under the Paris agreement, to expand green cover from 25 to 33% through adoption of such land use patterns which could be part of social forestry.

Mangrove Forest

Mangroves are salt-tolerant evergreen dense forests that grow in intertidal zones in tropical and subtropical estuarine regions and mud-flats. Mangroves are important means to control coastal erosion, also enhance sediment deposition which is essential to maintain the coastal ecosystems They are known to provide a range of ecosystem services, including carbon sequestration, coastal protection, and habitat for marine life. Mangroves also play a crucial role in freshwater conservation by acting as natural water filters and reducing the amount of saltwater intrusion into freshwater aquifers. Additionally, mangrove forests provide many economical, ecological, and environmental values to the people. According to India State Forest report (Anonymous 2015), in India mangroves spread is 4,740 sq. km which is about 3 percent of world's mangrove vegetation and 0.14 per cent of the country's total geographical area. As per the report of 2015, the district wise mangrove cover along the cities of Gujarat and Maharashtra, indicate mangrove cover decreased in Ahmedabad, Bharuch and Kachchh districts with reference to 2013, probably due to industrial pollution along the coast. Whereas, the mangrove cover has increased by 112 sq km as compared to previous assessment. Several studies have been conducted using remote sensing and GIS which show that there is increased erosion rate in coastal areas where mangrove forests have died. Root architecture of mangroves is such that it traps sediments and prevents erosion from waves and storms. Mangrove forests also play an important role in many other edaphic functions which includes nutrient cycling, facilitation of plant nutrition, disease suppression, water purification, and biological attenuation of pollutants (Shedage and Shrivastava 2018).

Conclusion

The paper highlights the issues of coastal erosion, sea water intrusion (SWI) and pressure of population, development, Industry, Agriculture, Horticulture, Aquaculture, Forestry, Livestock, Poultry, Goat rearing, etc on limited natural resources. Scientific, logical and sustainable Land Use Planning, with emphasis on rain water conservation, plantation of tree species and adoption of pressurized irrigation methods, irrigation schedules and optimizing water use are the ways to manage natural resources for longer term.

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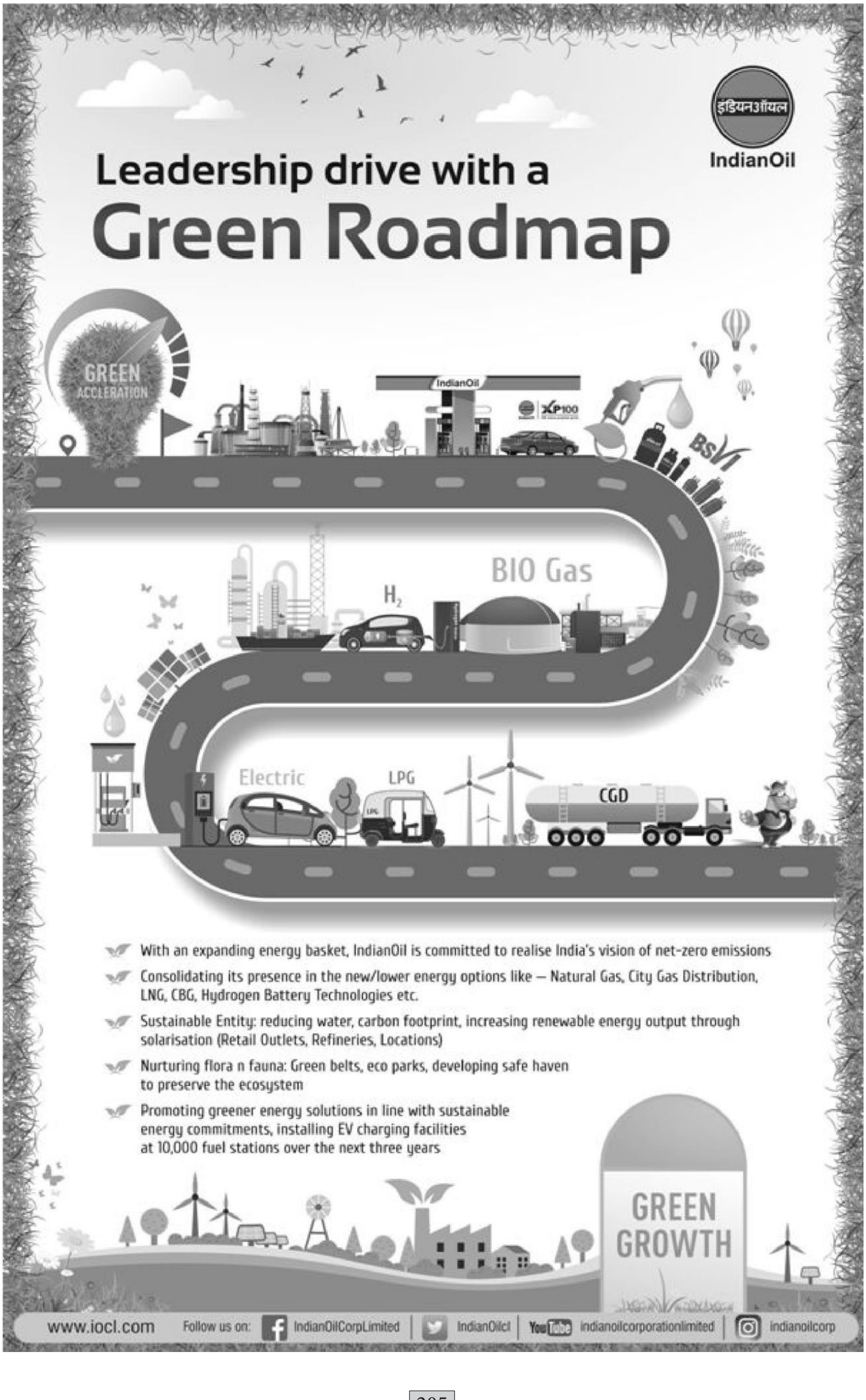
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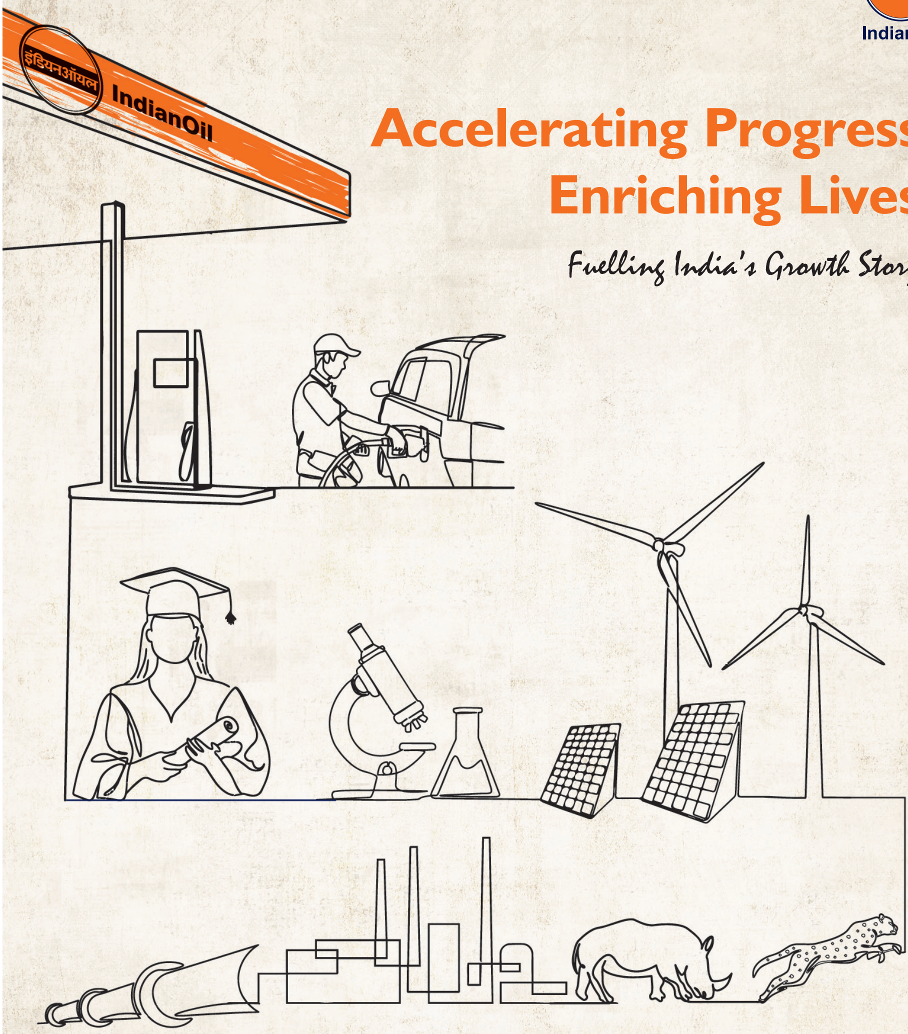

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