

Soil and water management practices for climate resilient rainfed agriculture

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Rainfed agroecosystems occupy a significant place in Indian agriculture covering about 72 mha, in arid, semi-arid, and sub-humid climatic zones, constituting nearly 51% of the net cultivated area. These areas contribute almost 100% of forest products, 73-90% of coarse grain cereals and pulses, 73% of oilseeds, 66% of cotton, and 40% of rice. Further, rainfed regions support 60% of livestock and 40% of human population and contribute 40% of food grains and several special-attributed commodities such as seed spices, dyes, herbs, gums etc. Owing to yield plateauing in irrigated area in most of the crops, the second green revolution must therefore explicitly embrace rainfed areas with special focus on pulses and oilseeds to ensure nutritional security and agricultural sustainability. In rainfed regions, a wide spectrum of agro-ecological conditions exists in different parts of country which are suitable for growing these crops throughout the year. There is sufficient scientific data to suggest that productivity of rainfed agriculture can be enhanced significantly on a sustainable basis if two basic natural resources, i.e. soil and rainwater, are well managed. In this article, major soil and water management practices for climate resilient rainfed agriculture are highlighted.

Key words: Climate resilient rainfed agriculture, Soil management, Water management

RAINFED agriculture is likely to be more vulnerable to climate change in view of its high dependency on monsoon and the chances of increased extreme weather events like delayed onset of monsoon, high intensity rainfall, seasonal drought, early withdrawal of monsoon etc. due to aberrant behaviour of south-west (SW) monsoon. About 74% of annual rainfall occurs during SW monsoon (June-September). This rainfall exhibits high coefficient of variation particularly in arid and dry semi-arid regions. Aberrations in SW monsoon strongly influence the crop productivity levels and these aberrations are likely to further increase in future. Numerous technological (e.g. cropping patterns, crop diversification, soil health management, rainwater harvesting, shifts to drought/salt tolerant

varieties etc) and socio-economic (e.g. ownership of assets, access to services, infrastructural support etc) factors will come into play in enhancing or constraining the current capacity of rainfed farmers to cope with climate change.

Resilient rainfed technologies

Technical adaptation measures range from change in production systems like adjusting planting dates, rotations, multiple cropping/species diversification, crop-livestock pisciculture systems, agroforestry, soil, water and biodiversity conservation and development by building soil biomass, restoring degraded lands, rehabilitating rangelands, harvesting and recycling water, planting trees, developing adapted cultivars and breeds, and protecting aquatic ecosystems to maintain long-term productivity.

Adaptation measures also take account of establishing disaster risk management plans and risk transfer mechanisms, such as crop insurance and diversified livelihood systems.

Rainwater management

Effective rainwater management is critical for drought mitigation and successful rainfed agriculture. *In-situ* soil and water conservation (SWC) practices improve soil structure and soil porosity, increase infiltration and hydraulic conductivity, and consequently increase soil water storage that helps crops to withstand moisture stress. These measures are more feasible and are practical proposition under most situations and can be adopted by individual farmers with less draught and amenable even for a small holder. The suitability of a practice depends on the topography of the field, temporal



Table 1. Location specific *in-situ* moisture conservations practices

Practice	Crops/cropping system	Remarks
Compartmental bunding	<i>Rabi</i> sorghum sunflower, safflower, chickpea, maize, pearl millet, cotton	The impact of the practice is more during sub-optimal rainfall years. It also significantly controls runoff. This practice is widely adopted in Bijapur, Bagalkot and Raichur districts of Northern Karnataka.
Conservation furrow	Finger millet + pigeon pea (8:2); groundnut + pigeon pea (8:2); soybean + pigeon pea (4:2); cotton + soybean (1:1)	It enhances <i>in-situ</i> moisture conservation, thus the crops can overcome the effect of dry spells during vegetative and/or reproductive stages of crops resulting in increased rainwater use efficiency, better performance of crops and additional net returns.
Broad bed and furrow (BBF)	Soybean, groundnut	BBF system helps draining out of excess water from the black soils. Further, the rainwater conserved in the furrows helps in better performance of crop during long dry spells.
Ridges and furrows	<i>Rabi</i> sorghum, pigeon pea + rice	The practice conserves 30-45% more moisture than farmers' practice, retains it for longer period (up to 60 days) and increases crop yield.
Ridge planting	Pearl millet	Provides enough aeration and porosity to soil for enhanced root growth, safe disposal of excess rainwater and reduction in soil loss apart from moisture conservation during low rainfall period.
Set furrow	Pearl millet-sunflower cropping, pigeon pea + groundnut (2:4)	Conserves more moisture and make it available for longer time to the crops. This helps to overcome the effect of drought.
Inter-plot rainwater harvesting	Sunflower, sorghum, chickpea	This practice makes possible to take up two crops even in drought years mainly by allowing rainfall infiltration into the soil profile.

and spatial distribution of rainfall, type of soil, crop, etc. Based on extensive research conducted at various locations in the country, several *in-situ* moisture conservations practices have been recommended (Table 1) and some of these practices are being adopted in significant areas in the country.

In addition to *in-situ* conservation, efforts need to be made to divert the surplus water into storage structures which can be used either as stand alone resource or in conjunction with groundwater for meeting the critical irrigation requirements. The

importance of rainwater harvesting has increased in recent years due to the increased rainfall variability, depletion of groundwater levels and raising temperatures. In relatively high rainfall regions, the strategy is to conserve as much rainwater as possible and to harvest the surplus water for life saving irrigation and also for enhancing the cropping intensity and to maximize returns from the harvested water. Apart from enhancing the availability of water by various methods, increasing the water use efficiency should be the focus by arresting various kinds of losses

associated with utilization of water. The advantages of supplemental irrigation are significant and considerable improvement in crop yields has been noticed at locations of various AICRPDA centers as given in Table 2.

Soil management

Soils in the rainfed regions constitute diverse orders with extreme variability in origin, parent material, water retention and nutrient status. In addition to the parent material, climatic variables like rainfall, temperature and sun-shine



In-situ moisture conservation through compartment bunding (left) and conservation furrows (right)

Table 2. Effect of one protective irrigation (5 cm) from harvested rainwater in farm ponds on yield of rainfed crops

Crop	Yield (kg/ha)	Yield increase due to irrigation (%)	Location/State
Sorghum	1,270	19	Anantapur/Andhra Pradesh
Sorghum	1,350	32	Bijapur (Vijayapura)/Karnataka
Maize	4,333	71	Arja/Rajasthan
Cotton	1,730	14	Kovilpatti/Tamil Nadu
Soybean	2,050	14	Indore/Madhya Pradesh
Castor	1,320	31	Hyderabad/Telangana
Wheat	2,143	25	Ballowal Saunkhri/Punjab
Pea	2,207	44	Varanasi/Uttar Pradesh
Barley	3,001	32	Agra/Uttar Pradesh
Safflower	1,014	48	Parbhani/Maharashtra

influence the type and key properties of soils in a given region. Soils hold the key to productivity and resilience to climate vagaries in rainfed agriculture in India. Loss of fertile soil as erosion, depletion of soil organic matter, emerging secondary and micronutrient deficiencies, soil compaction, surface crusting, loss of soil biodiversity have become potential limiting factors for productivity enhancement in these regions. Crust formation is a serious problem in Alfisols. Hard setting or crust formation results in difficulties in seeding, delay in emergence of plant, and restricted root growth. The germination of small seeded crops such as pearl millet, sorghum and finger millet are most affected.

Stabilizing or enhancing soil organic matter (SOM) is critical to minimizing risks of soil degradation and for ensuring sustainability of agriculture in rainfed areas. A severe depletion of SOM degrades soil physical quality, loss of favourable biology, and leads to the occurrence of multiple nutrient deficiencies. The

low SOM concentration along with low inputs are among the principal reasons of low production and large yield gap. The severe depletion of soil organic carbon (SOC) in rainfed agroecosystems in India has adversely impacted soil quality, crop productivity, and sustainability. Vertisols, Inceptisols, and Alfisols comprise a major share of SOC stocks in the top 30-cm-depth. Indeed, SOC stocks in the soil profiles across the country vary widely and follow the order Vertisols > Inceptisols > Alfisols > Aridisols. Some recommended practices for improving infiltration and water retention in soils include diverse crop rotations with legumes, and addition of farm yard manure (FYM), use of groundnut shells and other crop residues, green leaf manuring, etc.

Studies have revealed that integrated nutrient management significantly enhanced soil organic carbon (SOC) and associated soil function, and crop productivity. The long-term yield trend analysis (5-yearly moving averages) of

treatments in various long-term/permanent manurial trials (PMTs) conducted at different rainfed locations involving groundnut at Anantapur (Alfisols, initiated in 1985), finger millet at Bengaluru (Alfisols, 1978), *rabi* sorghum at Solapur (Vertisols, 1987), soybean at Indore (Vertisols, 1992) and upland rice at Varanasi (Inceptisols, 1985).

However, these results further suggested that in rainfed agroecology, long-term application of chemical fertilizers could not maintain optimum soil carbon content and crop productivity. On the other hand, the sole use of organic fertilizers also could not maintain the desired agronomic productivity in these areas due to inherently low nutrient status of these soils. Therefore, the application of chemical fertilizer coupled with organic fertilizer is important for these areas.

Site-specific nutrient management (SSNM): There is a need to supply the nutrients considering the crop need, soil fertility level and other agro-ecological situation, which is known as site specific nutrient management (SSNM). This approach although is considered as risky option under dryland situation due to uncertainty of rainfall distribution, integrating with suitable soil moisture conservation measures and cropping system yields better returns. At Solapur, under semi-arid Vertisols, application of fertilizer as per soil test (75:31 kg/ha N:P₂O₅) in *rabi* sorghum gave significantly higher grain (1,503 kg/ha) and stover yield (4,430 kg/ha). At Bengaluru, under



Rainwater harvesting in farm pond and efficient use for protective irrigation in crops



In-situ incorporation of green manure

semi-arid Alfisols, highest grain yield of finger millet (3,971 kg/ha) was recorded with site specific nutrient management approach (155:45:203 kg N, P₂O₅, K₂O/ha). A favourable B:C ratio (2.73) showed economic viability of site specific nutrient management technology for upscaling as against 2.04 in 100% N, P₂O₅ and K₂O (50:40:25 kg/ha).

Balanced nutrition/micro-nutrient management in rainfed production systems: Soils in most

parts of India not only show deficiency of NPK but also of secondary nutrients (S, Ca and Mg) and micronutrients (B, Zn, Cu, Fe, Mn etc.). Balanced nutrient application to crops based on the nutrient requirement to produce a unit quantity of yield and the native nutrient supplying capacity of soil improves crop yields while minimizing nutrient losses and cost of cultivation. Balanced nutrition (particularly optimum potassium

nutrition) contributes to mitigation of water stress conditions as K controls water relations in plant growth. At Arjia, under semi-arid Vertisols, recommended dose of N and P with all limiting nutrients (Zn, B and Mg) gave highest maize grain yield (2,474 kg/ha); at Bengaluru, under semi-arid Alfisols, rec. N and K+ lime @300 kg/ha + MgCO₃@150 kg/ha + Borax @10 kg/ha recorded a higher finger millet meangrain yield of 3,580 kg/ha; in sorghum at Kovilpatti, under semi-arid Vertisols, maximum grain yield of 1,624 kg/ha with 40 kg N/ha+20 kg P/ha+25 kg ZnSO₄/ha; at SK Nagar, in pearl millet under semi-arid Entisols, foliar spray of ZnSO₄ @ 0.5% + FeSO₄ @ 0.5% in maize gave maximum seed yield of 1,137 kg/ha with net returns of ₹ 13,833/ha, B:C ratio of 2.81 and rainwater use efficiency of 1.0 kg/ha-mm compared to water spray (762 kg/ha).

Real time contingency planning

During 1972-73, large scale scarcity of rainfall was experienced all over the country, particularly in region of Maharashtra, Karnataka and Andhra Pradesh. Roving

Table 3. Real time contingency interventions to cope with mid-season/terminal drought in diverse agro-ecosystems of India

Weather aberration	Real time contingency intervention	State/district/crop	Impact
Mid-season drought	Mulching	Assam/Lakhimpur/ginger and turmeric	- Helped in soil moisture conservation - Increased the yields of ginger and turmeric by 25-30%
	Conservation furrow	Karnataka/Bengaluru Rural/finger millet + pigeon pea intercropping and groundnut + pigeon pea intercropping	- Enhanced <i>in-situ</i> moisture conservation - Higher rainwater use efficiency - Increased crop yields by 25%
		Maharashtra/Akola/cotton	- Enhanced the soil moisture content - Increased the lint yield by 19%
		Maharashtra/Parbhani/soybean	Conserved the soil moisture and increased seed yield of soybean by 33%
	Protective irrigation	Tamil Nadu/Thoothukkudi/cotton	Increased crop yield by 18% compared to no protective irrigation
		Andhra Pradesh/Kurnool/groundnut and castor	Increased yield by 46% in groundnut and 20% in castor
		Gujarat/Jamnagar/groundnut and cotton	Increased groundnut pod yield by 26% and lint yield of cotton by 22%
Terminal drought	Protective irrigation	Assam/Lakhimpur/potato	Increased the tuber yield by 20-25%
		Gujarat/Banaskantha/castor and cumin	Increased the crop yields by 40-43%
		Gujarat/Jamnagar/groundnut and cotton	Increased pod yield of groundnut by 18% and lint yield of cotton by 20%
		Maharashtra/Parbhani/soybean	Gave 55% higher yield compared to rainfed crop (632 kg/ha)
		Tamil Nadu/Thoothukkudi/cotton	Higher seed cotton yield (1210 kg/ha) compared to rainfed crop (1065 kg/ha)
		Assam/Lakhimpur/potato	Gave 39% higher potato yield (26748 kg/ha) compared to farmers' practice

seminars were organized by the ICAR at different locations, at the end of which new phrases were coined, viz. contingent crop planning and mid-season correction. As a follow up, the AICRPDA (All India Coordinated Research Project for Dryland Agriculture) centres at Solapur and Bijapur collected data on these two aspects and after analysis of weather data for the past 100 years, listed the weather aberrations: (i) delayed onset of monsoon, (ii) early withdrawal of monsoon, (iii) intermittent dry spells of various durations, and (iv) prolonged dry spells causing changes in the strategy. Contingency plans, for each region, was a conceptual approach unique from AICRPDA project in developing location-specific contingent crop strategies which were first published in 1977 and with further refinements and updating in crops and varieties, the first document was brought out by AICRPDA in 1983 on “Contingent crop production strategy in rainfed areas under different weather conditions”.

To minimize the crop production and productivity losses and to improve the efficiency of the rainfed production systems, Real Time Contingency Planning (RTCP) was conceptualized in All India Coordinated Research Project for Dryland Agriculture (AICRPDA). RTCP is considered as “any contingency measure, either technology related (land, soil, water,

crop) or institutional and policy based, which is implemented based on real time weather pattern (including extreme events) in any crop growing season”. The major objectives of RTCP are to (i) establish a crop with optimum plant population during the delayed onset of monsoon; (ii) ensure better performance of crops during seasonal drought (early/mid and terminal drought) and extreme events; (iii) enhance performance, improve productivity and income; and (iv) enhance the adaptive capacity and livelihoods of the farmers. The RTCP is being implemented in two pronged approach i.e preparedness and real-time response.

Interventions like mulching with crop residues, *in-situ* moisture conservation, and protective irrigation from harvested rainwater in farm ponds were demonstrated to cope with mid-season drought in various field crops across different states. These interventions helped in coping with mid-season dry spells and gave 15-40% higher crop yields with additional net returns compared to farmers’ practices (Table 3). Terminal or late season drought normally occurs due to early withdrawal of monsoon and affects seed/grain filling and maturity stage of the crop. Terminal droughts are more critical as the crop duration gets shortened due to forced maturity. Interventions such as protective irrigation from harvested rainwater in farm ponds and mulching in different

crops gave 39-55% higher yields compared to farmers’ practices (Table 3).

SUMMARY

Droughts and famines are the general features of rainfed agriculture in India. Adoption of location-specific soil and water management practices is both essential and a prerequisite to make rainfed farming more economical and sustainable under increasing frequency of droughts, decrease in number of rainy days, and extreme and untimely rainfall. Much of the research done in rainfed agriculture in India relates to conservation of soil and rainwater, and drought proofing which is an ideal strategy for adaptation to climate change. Central Research Institute for Dryland Agriculture (CRIDA) and All India Coordinated Research Project for Dryland Agriculture (AICRPDA) have developed several location-specific doable technologies for soil and water management in rainfed farming. There is a need to upscale these technologies through KVKs, ATMA and several national/state programmes of the Governments to cope with weather aberrations and for realizing the productivity enhancements and large scale impacts.

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Improving water productivity and profit through drip irrigation

Drip irrigation (DI) was designed and used to enhance water productivity and profit in rice-based cropping sequence in an irrigated command of Odisha. Use of in-line DI system with 0.4 m emitter spacing, 2.1 litres/h emitter discharge and 1.0 m lateral-to-lateral distance in rice–capsicum–baby corn sequence enhanced productivity by 7.6 times higher than that of rice–rice system under surface irrigation (9.5 tonnes/ha/year). Further, the drip system in the cropping sequence generated higher profit (annual net return, ₹ 4.35 lakh/ha; benefit-cost ratio, 2.9) with 30% water saving resulting in 6 times higher water productivity (WP) compared with net return of ₹ 0.56 lakh/ha/yr with benefit-cost ratio of 1.6 and WP of 0.42 kg/m³ under rice–rice cropping in the command area.

Source: DARE-ICAR Annual Report 2018-19

Soil and water testing and soil health cards

Mini soil test kits were provided to all the KVKs to analyze the soil samples and preparation of soil health cards (SHCs). Workshop were organized to train the KVK personnel to handle the kit properly. Soil test campaigns were regularly arranged by the KVKs to make farmers aware of the importance of soil testing and fertilizer recommendation. Feedback was collected by KVKs on the use of SHCs from farmers regularly. Every KVK conducted training programme/workshop inviting farmers and train them how to use the SHCs season-wise and crop-wise as per the prescription (fertilizer recommendation) mentioned in the SHCs. Soil samples (8,33,107) were analysed and 8,79,574 soil health card were distributed among the farmers during the reporting period.

Source: DARE-ICAR Annual Report 2018-19

