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Dryland Agriculture in India
- Status and the Way Forward

Often the terms 'drylands' and 'rainfed regions' are used synonymously. Though they overlap to a large extent, dryland area is a piece of agricultural land having no source of irrigation including groundwater. Dryland Agriculture is defined as cultivation of crop entirely with rainwater received during the crop season or stored/ conserved soil moisture or supplemented with harvested rainwater. Time and again the crop experiences mild to very severe moisture stress during cropping period in dryland areas. Drylands are characterized by having) limited rainfall up to 1000 mm; ii) shortage of moisture availability; iii) growing season of less than 200 days;iv) single crop or intercropping system, and v) constraints of water and wind erosion.

There is no single agreed definition of the term drylands. Two of the most widely accepted definitions are those of FAO and the United Nations Convention to Combat Desertification (UNCCD, 1994). FAO has defined drylands as those areas with a length of growing period (LGP) of 1–179 days (FAO, 2000); this includes regions classified climatically as arid, semi-arid and dry sub-humid. The UNCCD classification employs a ratio of annual precipitation to potential evapotranspiration (P/PET). UNCCD (United Nations Convention to Combat Desertification) defines drylands based on aridity index (Ia) computed as ratio of mean annual precipitation (P) to mean annual potential evapotranspiration (PET). Accordingly, areas with arid (Ia=0.05-0.20), semi-arid (Ia=0.20-0.50) and dry sub-humid (Ia=0.50-0.65) climates are termed as drylands (UNCCD, 1994). While about 40 percent of the world's total land area is considered to be drylands (according to the UNCCD classification system), the extent of drylands in various regions ranges from about 20 to 90%.Raju et al. (2014) computed aridity index using the district level annual rainfall and PET data for years 1971-2005 and identified districts in India having dryland climates. Net sown area (mostly average of two years: 2007-08, 2008-09) of districts with dryland climates adds up to 85 m ha (approximate). A map showing dryland districts is furnished as Fig. 1.

Drought Prone Districts in India - Revisited

As per UNCCD criteria some of the districts of Punjab, Haryana and Uttar Pradesh states which are part of Indo-Genetic belt fall under dryland climate. However moisture inadequacy is not very acute in these

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districts due to assured sources of irrigation. Irrigation helps in bringing stability in production of crops and livestock. In view of this a technical committee constituted by MoRD in 1993 under the chairmanship Prof. C.H. Hanumantha Rao to review the Drought Prone Area Programme (DPAP) and Desert Development Programme (DDP) developed a criterion based on moisture index and share of net irrigated area to net sown area to identify districts to be covered under DDP and DPAP (MoRD, 1994). Moisture index is computed as (P-PET)/PET. According to this criterion, the districts where arid ecosystem exists (moisture index value less than –66.7) and net irrigated area is not more than 50% were eligible to be covered under DDP. The districts with semi-arid ecosystem (with moisture index range –66.7 to –33.3) and net irrigated area not more than 40% were made eligible for coverage under DPAP. The districts with dry sub-humid ecosystem and net irrigated area not more than 30% were also made elible for coverage under DPAP. Average irrigation statistics (mostly 2007-08 and 2008-09) and moisture index based climate assessed by Raju *et al*. (2013) based on recent data sets were employed in the dual criteria and eligibility of districts to DPAP / DDP was evaluated (Venkateswarlu *et al*., 2014). The map showing the districts eligible for DPAP and DDP is furnished as Fig 2. There are 22 districts eligible for DDP and 121 districts eligible for DPAP totaling 143 districts.

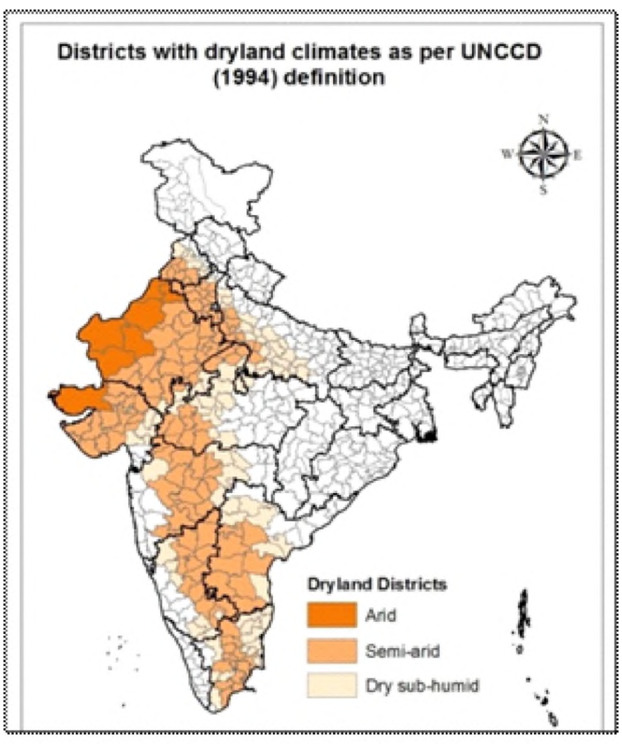

Fig 1. Districts with dryland climate

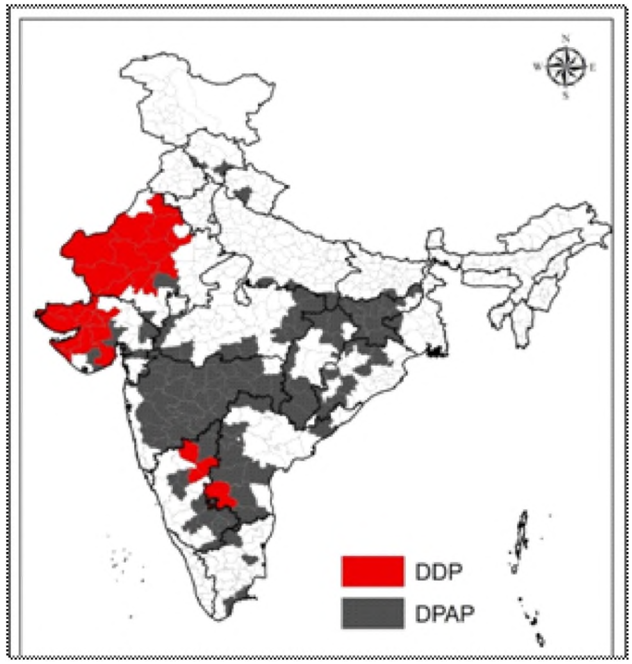

Fig 2. Districts eligible for DPAP and DDP

Dryland Agriculture Production Systems

Dryland agriculture production systems in the country are diverse and heterogeneous. They are grouped in to five classes viz. i) Rainfed rice production system; ii) Coarse nutritious cereal based production system; ii) Oilseed based production system; iv) Pulse based production system and v) Cotton based production system.

Though these crops require relatively less water, they present much bigger problems addressing some of which is beyond the realm of any single stakeholder organization. For example, coarse cereals suffer an eroding demand because of reasons such as changing food habits, government policies related to input subsidies, food supply and procurement. Similarly, pulses are not so breeding-friendly in the sense that genetic improvement for higher yields is more difficult compared to crops such as rice and wheat. The difficulty in breaking the yield barriers in case of pulse crops is reflected in the rate of growth in yield during the last four decades. Crops such as pigeonpea, castor and cotton are essentially long duration crops and hence are more prone to moisture stress during the later stages of crop growth and are also sometimes subjected to heavy rains during and after flowering resulting in considerable yield losses. Tons

This sector currently produces 40% of the food grains and supports two-thirds of the live stock population. Despite increase in average productivity levels from 0.6 tonnes in the eighties to 1.1 tonnes at present, large yield gaps exist in several crops and regions between research stations and farmer's fields.

Dryalnd Agriculture Research: History

The Green Revolution in mid-sixties, though a boon to Indian agriculture, ushered in era of wide disparity between productivity of irrigated and rainfed agriculture. Alarmed by such a situation, during Fourth Plan (1969-74), the emphasis was to focus attention on hither to neglected farmers of the dryland regions to participate meaningfully in the agricultural development process. This socio-economic imbalance led to a serious rethinking and a comprehensive network research program was initiated to stabilize the performance of the then introduced hybrids of coarse cereals in rainfed/dryland region and to moderate the periodic drought related adverse impact on total agricultural productivity. Further, droughts of mid-sixties catalyzed the Govt. to invest on dryland research significantly. In1970 the ICAR launched All India Coordinated Research Project for Dryland Agriculture (AICRPDA) at Hyderabad, in collaboration with the Canadian International Development Agency (CIDA) with 23 centers and Co-coordinating Cell at Hyderabad. CRIDA was established during 1985 by upgrading the All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Hyderabad centre to work on development of suitable technologies to enhance the productivity in rainfed areas. CRIDA, along with two All India Coordinated Research Projects namely on Dryland Agriculture and Agrometeorology with about 25 centers each located in different parts of the country, strives towards development and popularization of location specific rainfed technologies for productivity enhancement.

The systematic research in dryland agriculture was initiated by ICAR in 1970 with start of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in collaboration with Canadian International Development Agency (CIDA) and AICRPDA-CIDA collaboration was in three phases i.e.1970-75, 1976-82 and 1982-87. During 1970-1987, the sound foundations of systematic and location-specific research were laid out across AICRPDA centers. The location specificity of the technology was emphasized with "low monetary input", i.e. the basic crop production practices like time of seeding and plant population-geometry in relation to rainfall, and weed management, crop substitution and cropping systems as a necessary input for improved production. The emphasis on intercropping research was to identify the regions where intercropping was feasible and worthwhile to increase in cropping intensity and secondly, to compare the productivity and stability of intercropping versus monocropping in agro climatic-regions where only a single crop is feasible in a year. The research strategy for each region consisted of screening of different crops for compatibility in intercropping systems, modifying planting patterns, such as *paired row planting,* identifying optimum row ratios for efficient moisture and nutrient utilization by component crops, identifying the best cultivars for the component crops and determining the optimum N and P doses for intercropping systems. The significant area identified was tailoring the technology to the aberrant weather situations. The focus on rainwater management research was on identifying efficient methods for crop life saving irrigation, *in situ* moisture conservation by tillage, continued focus on identifying efficient crops and cropping systems, crop husbandry for weather aberrations and alternate or multiple land use. The research continued on intercropping and double cropping could ensure stable optimal yields and maximize profits in relation to agro climatic resources, with further refinement of the *systems* through identification of genotypes, manipulation of sowing and harvesting dates and plant populations and fertilizer use. The pulses and oilseeds formed important components of the cropping systems research (AICRPDA, 2003).

The dryland research amply demonstrated that yield of dry land crops could be increased by at least 100% with improved varieties and sowing methods and higher yields with advancement of sowing dates, particularly post rainy period in Deccan region, minimizing the risk with split application of N, and alternate crops for aberrant weather situations. Dry seeding is recommended for the locations/soil types where the conditions (soil) do not permit sowing operations with the onset of monsoon. Across the AICRPDA centers, probable and efficient crop growing periods were established based on rainfall, potential evapotranspiration and water retaining capacity of soils. Kaolin was identified as the most effective antitranspirant for controlling the transpiration losses of barley and sorghum. In black soils regions, with 500 to 1000 mm rainfall, the productivity of upland rainy season crops could be substantially improved by providing furrows graded to 0.2 to 0.3 % slope, to transmit excess rainwater. Another milestone in dryland research was r*efinement of cropping system technology i.e.* in case of rainy season crops, choice of crops and varieties could be decided by the rainfall pattern and length of effective growing season, however in post-rainy season crops grown on conserved soil moisture, the available soil moisture in the profile at the sowing time decided choice of crops. With the advent of high yielding and input responsive varieties to suit different situations, the agriculture became more '*Production oriented*'.

The concepts of off-season tillage, and life saving irrigation with harvested rainwater for better crop production were established. In chronic drought prone areas, deep tillage (20-30 cm) was found specifically applicable to soils having textural profiles or hard pans. Under uni-modal (<500 mm) rainfall situation in semi arid regions with shallow Alfisols, sowing across the slope and ridging later was useful. In black soils, deep tillage alone was of no avail. Tillage combined with compartmental bunding was found to be a most effective soil management practice for Vertic Incept sols. With rainy season cropped Vertisols (unimodal rainfall regions), water surplussing is an integral part of in situ moisture conservation. In bi-modal medium (500-750 mm) rainfall representing semi-arid Alfisol, graded border strips were found advantageous. Surface mulching with crop residues like sorghum and maize stubbles, dry grass, wheat straw and pigeonpea stalk prevented moisture loss and prolong the moisture retention period and enhanced yield of crops. The *year round tillage* as a means of control of weeds and conserve soil moisture was crystallized into a concept of great significance to dry lands. Deep tillage increased the yields of crops across the climates and soil types. The ridges and furrows always increased the yield, however with more effectiveness during moderate drought (AICRPDA, 2003).

The research on intercropping systems (ICSs) suggested that additive series was most successful with base crops as sorghum, maize, pearl millet, pigeonpea, safflower and wheat, wherein the land equivalent ratios (LERs) of the additive series were greater (with average of 23% more) than replacement series with multiple benefits of higher output and returns, spread labour peaks, maintenance of soil fertility (with inclusion of legume) and stability in production. Intercropping of fast growing legumes like cowpea and greengram as cover crops benefitted the base crop in better resource efficiency. The performance of the ICSs were strongly correlated with the amount of seasonal rainfall, when it was the above normal, optimum productivity was achieved; under normal rainfall conditions, fairly high values of land equivalent ratios were achieved; and under low rainfall conditions, one of the two crops reasonably yielded providing an insurance against the risk due to weather aberrations. Stable and economically viable double and intercropping systems were evolved with predominant crops of the region as base crops and pulses and oilseeds as intercrops for various rainfall and soil type regions with potentials of higher productivity, income and high land and resource use efficiency over time and space that increased cropping intensity to 150 to 200%. Several crops were screened for intercropping systems across the country. Pigeonpea either as base crop or intercrop performed better, particularly in sorghum, cotton and pearl millet based intercropping systems (AICPRDA, 2003).

Crop substitution concept was evolved in which the performance of various new crops was evaluated *vis-a-vis* traditional crops, for e.g. in Vertisols of Bellary, sorghum was efficient than cotton. The cropping intensity could be increased considerably depending on the soil types and moisture availability period. However, the duration of the crop cultivars influenced the selection of a cropping system. Hence, the research in this area clearly brought out that in the high rainfall dryland (> 1000 mm) regions of Orissa, and eastern Madhya Pradesh, a second crop could be grown in the residual moisture after a 90 days duration variety of upland rice than 120 days duration, similarly in the Vertisols of Vidarbha (Maharashtra), a change of 140 or 150 days sorghums to about 90 or 100 days cultivars provided an opportunity to grow chickpea or safflower in sequence. Double cropping was possible only in areas receiving more than 750 mm rainfall with a soil moisture storage capacity of more than 200 mm. Another significant contribution of agronomic research was the identification of the most compatible genotypes of the component crops of the system for a higher system's productivity.

The experiments on alternate land use systems (ALUS) for arable and marginal lands were initiated at AICRPDA in 1981. *Leucaenalecocephala* based forage alley cropping system was developed at Hyderabad with the multiple objectives like forage, forage- cum-mulch, and forage-cum-poles. The ALUSs developed were tree farming, ley farming (*Stylosantheshamata* with sorghum rotation), silivipasture (*Leucaenaleucocephala* + *Stylosantheshamata* + *Cenchrusciliaris*) agro-horticulture (guava/custard apple/pomegranate/ber based). *Leucaenaleucocephala* is the most popular tree species to serve as hedge-row in the alley cropping system. Studies at AICRPDA revealed that *Dicanthium, Sehima* and *Lasiurus* are suitable for severe drought prone areas while *Cenchrusciliaris*, *Panicum maximum* and *Urochloa* were for moderate drought prone areas. *Stylosanthushamata,* a pasture legume, was identified for improvement of soil fertility and as quality fodder for alfisols of Hyderabad.

During 1972-73, large scale scarcity of rainfall was experienced all over the country, particularly in the scarcity region of Maharashtra, Karnataka and Andhra Pradesh. Roving 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, dry land centers 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; iv) prolonged dry spells causing changes in the strategy ; and v) prolonged* *monsoon.* Scientists at Solapur, Bijapur, and Hyderabad worked on these aspects and developed *Contingent crop planning strategies for delayed on set monsoon* (AICRPDA, 1983). The research efforts made in this scarcity region by introduction of safflower as a sole crop in scarcity zone of Maharashtra ultimately augmented the oilseed production. *Contingency plans,* for each region was a conceptual approach unique from AICRPDA project in developing location specific contingent crop strategies.

The research, 1987 onwards, was focused on evaluation of the most efficient crops and their varieties for each agro climatic location. Most efficient crop varieties have been identified based on a continuous evaluation and screening both at research station followed by farmers' fields. With the base crop of 100 days duration, for intercropping, varieties of 140-150 days duration on deep moisture - retentive soils and 60-70 days duration on medium deep soil were highly successful. A pool of germplasm of short duration under exploited crops such as horse gram has been screened and promising lines identified for increasing cropping intensity by sequence/ intercrop. In case of plant density, the average productivity over varying plant densities is positively correlated with sustainability in most of the situations. Sustainability in yield due to plant density is interacting with crop, variety, season, rainfall, soil type and fertilizer. When fertilizer was applied the sustainability index started decreasing at a lower plant density compared to the situation where fertilizer was applied at a higher plant density. Another interesting point is that in the case of post-rainy season sorghum, the sustainability started decreasing at a lower plant density level in the case of variety (M-35-1) compared to hybrid (CSH-8R) grown on shallow (>30 cm) soils. With sufficient rainfall (usually > 800 mm) double cropping was possible and out of the two crops, one could be short duration (60-70 days, usually legume), and another could be long duration of 110-120 days (usually cereal). At Phulbani, Rewa and Ranchi, sequential cropping was very much possible while with more success in selection of suitable crops and their sequence. Short duration (60-70 days) legumes such as greengram/blackgram or early cowpea followed by 100-120 days cereal crop was an ideal sequential cropping system while one cereal in the sequence was useful to meet grain and fodder requirements. In regions where rainfall was more than 1000 mm (Rewa and Ranchi), upland rice-chickpea/ lentil was a proven sequence. Successful intercropping was when the optimum plant population of base crop through the row arrangements while maintaining the plant density of companion crop/intercrop near optimal (range could be 75 -100%). At Hyderabad, in shallow soils sorghum + pigeonpea (2:1) performed better with yield advantage (both grain and fodder) up to 20% under varied rainfall situations. Pigeonpea had been found to be unique and highly preferred component crop across production systems (AICRPDA, 2003).

The studies conducted across AICRPDA centers showed that 1 kg of fertilizer N produced additional grain yield varying from 4.3 to 38 kg in a variety of crops (rice, sorghum, pearlmillet, *rabi*sorghum, wheat, safflower and mustard) grown under different rainfall environments and diverse soil types. Integrated nutrient management (INM) studies have established the value of a number of naturally occurring nutrients containing (organic manures) and generating (biofertilizers) sources to augment overall nutrient turnovers for soil fertility management. Green manure was found to be a dependable source of several plant nutrients. Typically, it could meet half the N requirements of a crop. Inclusion of legumes in a rotation benefitted the succeeding crop equivalent to 10 30 kg Nha^{-1}. Short duration legumes such as cowpea benefitted much more. INM in combination with legume based crop is recommended for higher productivity. INM systems, besides nutrient supplementation, enhanced soils' ability to hold additional water and produced resulted in favorable soil biological interactions. Schemes to generate green manure in a non-competitive way during the no cropping season and bund farming have been worked out. This has opened up a new vista to make green manuring a viable option. Long term INM trials conducted for more than 35 seasons at AICRPDA centers indicated that fertilizer cost can be reduced by substitution of fertilizer with organics. In most of the situations, the yield sustainability was higher when the recommended dose of fertilizer was applied. Further, in case of cereals, higher sustainability was obtained when the recommended dose of nutrients was applied through chemical sources. In case of oilseeds, however, the recommended dose applied half through chemical fertilizer and the other half through organic source led to higher sustainability values. Available nitrogen, organic carbon and phosphorus content in soil were increased with organic fertilizer application. Application of crop residues in combination with chemical fertilizer resulted in higher sustainable yield and maintained higher levels of nitrogen, phosphorus and organic carbon. Green leaf manure proved promising in increasing the sustainability in yield and improving the organic carbon, infiltration rate and hydraulic conductivity of the soil.

The rainwater haresting in farm ponds and efficient utilization through supplemental/protective irrigation to annual crops and fruit crops proved to be beneficial . Harvesting runoff water and storage in farm ponds could be a distinct possibility in red soils of Karnataka. Ponds may be 200 m^3 for 0.6 ha catchment and 2000 m^3 for 6 to 7 ha catchment areas. Nearly 50% of the stored water can be used for protective irrigation. Under severe drought, at Arjia, protective irrigation increased yields by 377 over 1004 kg/ha in maize. During the experimental period of 7 seasons, there was a total failure of crop in one year and drought occurred in 3 seasons at Arjia. In medium deep black soils of Bijapur, Bellary, and Solapur, the effect of one minimal irrigation (4 to 6 cm) on the yield of rabi sorghum was phenomenal. In red lateritic soils of Bangalore, the late sown crops such as finger millet or long duration crops such as chillies or cowpea sown in May are likely to be more benefited by one protective irrigation of 5 cm than two irrigations of 2.5 cm each (AICRPDA, 2003).

In the *Post 1985 era*, the dryland research was much important due to shift from field crops to dry land horticulture plantation, particularly in shallow and sloppy lands. Techniques for rehabilitation of marginal lands for planting annual and perennial crops by restructuring the planting site were devised through fertility improvement by addition of tank silt, composted/farmyard manure, black soil etc. With planting site improve-ment, a noticeable improvement in crop establishment, survival and yielding ability occurred. Studies at CRIDA have indicated that ring weeding and *in situ* moisture conservation besides micro site improvement were essential to improve the survival of fruit tree seedlings in dry lands. Water supply to the plant can be improved by water harvesting using situ or *ex situ* system.

The opportunities for *crop diversification* were explored. Based on the research information for the past 40 years, a new approach was identified for horizontal and vertical diversifications potentials of rainfed cropping systems in typical rainfed districts in India, which were given for five major crop based production systems viz. rice, oilseeds, pulses, cotton and coarse cereals under the Simpson crop diversification indices of 80-100%, 60-80%, 40-60% and less than 40%, as well as under different soil degradation status (Vittal and Ravindra Chary, 2007). Studies on high value crops like at CRIDA and in other organizations, medicinal and dye crops (senna, ashwagandha, dye crops etc) aromatic (lemon grass, palmarosa, vetiver, basil etc.) and dye yielding (Indigo, Bixa, Henna etc) either sole or in intercropping systems indicated a large scope for crop diversification with these crops in dry land agriculture for risk minimization, higher income and quality produce.

During 2001-2005, an entirely new approach of *Crop planning as per Soil-site suitability* was conceptualized under NATP-Mission Mode Project on Land Use Planning for Management of Agricultural Resources in Rainfed Agro ecosystem where in 400 interventions were demonstrated on 132 soil-sub groups on varying topo-sequences in 16 micro-watersheds. This provided much needed land use diversification from the traditional rainfed land utilization and indicated micro level variations of soils (phases of soil series) and management practices on a topo-sequence are the prime factors influencing land productivity which increased from 30 to 50 per cent and in few cases more than double. The soil-site suitability criteria were developed for 41 field, horticulture and high value crops.

Research on integrated farming systems was started at AICRPDA centers in 1990s (AICRPDA, 2003) and also under NATP-PSR and NATP-IVLP-TAR projects during 1999-2006. At Kovilpatti, an IFS model for 0.4ha comprising sorghum+greengram (0.16 ha) + maize + cowpea (0.08 ha) + clusterbean /senna (0.04 ha) + poultry (20 broiler birds) +*Kanni*goats (4) + *Vembur* sheep (6) + dairy - cross bred cow (1) was suggested which could give more sustainability with higher net returns, employment generation and increase in soil fertility. Other IFS modules suggested were, agroforestry+sheep based IFS at Anantapur, cereals, pulses and oilseeds based IFS modules for 1 ha at Hyderabad and most importantly at Arjia viable IFS modules were developed with the components of crop, small ruminants, agroforestry systems for small and marginal holdings, which were included in National Livelihood Mission programme in Bhilwara district (Rajasthan).

The benchmark Permanent Manurial Experiments initiated at 18 Centers in 1984 across diverse rainfed cropping systems serving as platforms for intensive research on carbon sequestration, nutrient use efficiency, development of data sets for C modeling, LCA and overall soil quality index development. The long term experiments on tillage and nutrient management at 19 Centers since 2000, formed the basis for development of resource conservation and Conservation Agriculture (CA) research initiative in rainfed production systems under ICAR-CRP. These outcome of these experiments led to developing soil quality indicators for diverse dryland agro ecologies and production systems. A summary 0of the major research achievements from the above 11 centers are briefed below.

Dryland Agriculture Research: Salient Achievements

The following 13 AICRPDA centers are located in **dryland districts** identified under DPAP/DDP programme in the country.

Mean Annual Rainfall (mm) /Climate	AICRPDA centers (MARF)
500- 750 / Semiarid hot dry	Anantapuram (554) ;Arjia (656); Bijapur (595); Kovilpatti (723); Rajkot (590); Solapur (732)
750 -1000 / Semiarid hot moist	Bengaluru (926); Parbani (901); Akola (824)
1000-1250 / Sub humid hot dry	Ranchi/Chianki (1179); Rewa (1088)

ResourceCharacterization

- *Six drought regions identified based on natureandextent of drought, climate crop season and soil type viz.* drought regions identified viz.DR-I: Chronic Drought in Arid Marginal Rainy Season Aridisols); DR-II: Chronic Drought Regionin Arid Sub-marginal Rainy Season Vertisols and Alfisols); DR-III: Chronic Drought Region in Dry Semi-arid Delayed Rainy Season; Vertisols and Alfisols); DR-IV:Chronic Droughtin Dry Semi-arid Post Rainy Season Vertic/Vertisols); DR-V: Ephemeral Droughtin Wet Semi-arid Rainy Season Vertisols/Alfisols); DR-VI: Apparent Droughtin Dry Sub-humid Alfisols/Oxisols Regions).
- *Delineated Rainfed Agro–economic zones:* For developing Agri entrepreneurships network with crop diversification and value addition in rainfed regions *(CRIDA Vision2030).*
- *Characterized Rain water harvesting of potential zones* in the agro-climatic domains of AICRPDA centers.

Rainwater Management

- *Developed location specific in sit moisture conservation practices for diverse dryland agro- ecologies based on* rain fall and soil types viz. deeptillage,compartmental bunding, inter-*plot* rain water harvesting techniques, conservation furrow, broadbed & furrows, raised bed & furrow system, ridges & furrows, tiedridges, zingterracing, mulching techniques, etc.
- *Ex-siturain water management:* Based on catchment- storage-command area relationship, standardized rainwater harvesting structures viz. farm pond and other WHSs for diverse rainfall and soil types and efficient rain water utilization for higher water productivity.
- *Developed location-specific groundwater recharging techniques/Models* at Parbhani, Bijapur, Bangalore and Rajkot centers with efficient filtering mechanisms.

Cropping Systems

- *Identified potential cropping systems and drought vulnerability based on rainfall and soil types:* For rainfall zones of 350-650mm, in Alfisols, shallow Vertisols, Aridisols and Entisols with growing season of 15 weeks, single cropping; for rainfall zones 350- 650mm, indeep Aridisols and Inceptisols, with growing season of 20 weeks, Either rainy or post- rainy season crop and in deep vertisols, post-rainy season cropping for rainfall zones of 650mm - 800mm, in deep Vertisols, Alfisols and Entisols, with growing season of 30 weeks, double cropping; and >1100 mm rainfall zones, indeep Alfisols/Oxisols, with >30 weeks growing season, double cropping is possible.

Soil Management

- *Identified emerging nutrient deficiencies in rainfed production systems:*
- INM studies have established that *50% of recommended N through organic sources and 50% of N through inorganic sources* along with micro nutrients and bio fertilizers augment edoverall nutrient turnovers for soil fertility management. Green manure could meet half the N requirements o a crop. Inclusion of legumes in arotation produced benefit to the succeeding crop equivalent to 10-30 kgNha-1.
- *Characterized soil organic carbon stocks in rainfed production systems:* Organic C stocks varied Vertisols, Inceptisols, Alfisols, Aridisols in decreasing order. Inorganic C and total C stocks were larger in Vertisols than in other soil types. Soil organic C stocks decreased with depth in the profile, where as in organic C stocks increased with depth. Among the production systems, soybean, maize and groundnut-based systems showed greater organic C stocks than other production systems.
- *Carbon sequestration strategies identified for diverse rainfed production systems:* Conjunctive use of chemical fertilizers and organic manure resulted in higher sustainable yield index (SYI) over unfertilized control and

sole application of either chemical fertilizers ororganic manures. The mean annual C input were recorded maximum in soybean system followed that in rice and groundnut systems. The soil organic carbon content increased from 0.23% to 0.39% at Anantapur, 0.23% to 0.39% at Bangalore, 0.36% to 0.56% at Solapur due to different INM practices.

- *The carbon foot prints (TgCE ha-1year-1)* were higher in cereals cropping systems followed by oil seed and pulse systems.The carbon foot prints per unit amount of yield (Tg CE Mg-1 grain) showed higher for rice (2.8800) – lentil (6.1463) sequence in Inceptisols.
- *Identified key Soil quality indicators in diverse rainfed agro ecologies:* Organic carbon (OC), available N, P, K, S, exchangeable Ca, Mg and DTPA extractable Zn were emerged as key chemical soil quality indicators in most of the rainfed soils. Among these to biological and physical soil quality indicators, dehydrogenize activity, microbial biomass carbon and labile carbon, bulk density and mean weight diameter (soil structure) figured as predominant indicators.
- *Micronutrientresearchinrainfed production systems:* AtArjia, recommended dose of N&P with all limiting nutrients (Zn,BandMg) gavehighestmaize grain yield(2474 kg/ha);at Bengaluru, rec.NandK+ Lime @300 kg/ha + MgCO3 @150kg/ha + Borax @10kg/ha recorded ahigher finger millet mean grain yield of 3580 Kg/ha; in sorghum at Kovilpatti, maximum grain yield of 1624 kg/ha with40 kg N/ha +2 0kg P/ha + 25 kg ZnSO4/ha.
- *Identified foliar spray of potassium for drought irrigation*: Multi-location experiments on diverse soil types and crops viz., Solapur, Maharashtra (*rabi* sorghum,Vertisol); Arjia, Rajasthan (maize, Inceptisols); Viswanath Chariali, Assam (toria, Inceptisols); Rajkot, Gujarat (groundnut, Vertic Inceptisols) and Jamnagar, Gujarat (chickpea,Vertisols) indicated, spray of 1% KNO3 @ 35 and 55 days after sowing (DAS) in *rabi* sorghum, etc.
- *Quantified tank silt application indicated increased* yields by 230% compared ton on tank silt applied sites at Anantapur, Arjia, Bangalore and Solapur centers. ADSS developed for quantified tank silt application.
- *Low till farming strategies identified:* Conventional till age was superior at Bangalore for finger millet under semi-arid Alfisols; for pearl millet under semi-arid Vertisols of Solapur;for rice under moist sub humid Alfisols/ Oxisols of Phulbani; soybean under moist sub-humid Vertisols of Rewa and groundnut under semi-arid Alfisols of Anantapur.

Small farm mechanization in dry land agriculture

- Designed, developed, evaluated and popularized cost effective and energy efficient tools, farm implements/machinery for various agricultural operations including rain water management in dryland crops. Farm mechanization reduced 20-59% operation cost, saved 45-64% in operation time, saved 31-38% seed & fertilizer and increased productivity of dryland crops by 18- 53% .

Real-Time Contingency Planning

- *Conceptualized in AICRPDA since 2010* as two pronged approach i.e preparedness and implementation to cope with delayed onset of monsoon and inseason drought with various real-time soil, crop, nutrient, rainwater and energy management interventions.
- *Identified suitable crops and varieties to cope with delayed on set of monsoon:* Forex. at Parbhani for 18 days delay, pigeonpea cv. BDN711

Alternate Land Use Systems in dryland areas

- Alternate land use systems, particularly dryland horticulture and agri-horti systems were identified for different rainfall zones and soil types which included agri silvi culture, agri-horticulture and silvi pasture systems: *Aonla* + finger millet/cow pea at Bangalore.
- *A3 x 3 Productive Farming Systems Matrix in Rainfed Agriculture developed: Land* Capability based Productive Farming Systems are identified for drought prone regions based on land capability, rainfall, and soil orders and the outcome of research information generated at AICRPD Acenters.
- Identified rainfed farming systems viz. at Bangalore, crops + dairy + sheep + goat + poultry + sericulture + piggery; at Kovilpatti (TamilNadu) showed that crop + goat (4) + poultry (20) + sheep (6) + dairy (1); at Bijapur crops, horticulture, goat and poultry and at Anantapur, sheep rearing (10no.) and groundnut cultivation (1ha) and groundnut cultivation (1ha) +1 jersey cow.

Contribution to Dryland Agriculture Development

- 1974 - Integrated Dryland Development Project
- 1977 - Desert Development Programme
- 1982 -Special programme on Integrated Watershed Management
- 1984 - ICAR-Model Watershed Programme 30 model watersheds (500-1000ha), in 13 states were assigned to AICRPDA for technological backstopping
- 1986 - with the success of Model watersheds, GoI launched National Watershed Development Programmes in Rainfed Area (NWDPRA) in 15 states
- 2000 onwards – Development of policy instruments in rainwater harvesting and management; vulnerability of agriculture to climate change; contingency crop planning and its implementation to tackle weather aberrations, etc. This has led to promulgation of suitable policies by state governments for their implementation in rainfed regions for the benefit of the farmers. Policy on farm pond/ percolation tanks in Andhra Pradesh, Maharashtra, Madhya Pradesh, Karnataka.
- 2011 onwards - technical backstopping to preparation of District Agriculture Contingency Plans for 643 districts in the country. Contributed to preparation of Compensatory *rabi* production plans during 2014, 2015, 2016.
- 2016- Revised Manual on Drought Management by DAC&FW, MoA & FW, GoI.
- 2014 onwards –Integration of doable rainfed technologies in State action plans under National Missionon Sustainable Agriculture (NMSA); MGNREGA, IWMP, RKVY, NFSM, NHM; Dryland Farming Missions of Karnataka, Maharashtra and Comprehensive District Agriculture/Land Development Plans of various districts.
- Further, contributed to policy formulation by working with the Planning Commission, National Rainfed Area Authority (NRAA), MoA & FW & MoRD, GoI.

Dryland Agriculture Research: Challenges Ahead

Multiple abiotic stresses are a key challenge for dryland crops in future. In the same season, crops can face drought in early part and water logging in the later due to erratic rainfall distribution. Heat stress is another factor which could influence crop yields particularly during rabi season. An important area of CRIDA's work is to tap the diversification of dryland regions with region-specific models of integrated farming systems including livestock and fisheries. Such systems will help in cushioning the stakeholders against risks (drought) which are becoming more frequent in recent years. Opportunities also exist for diversifying to fruit, fodder, fuel wood and timber crops. Opportunities exist in the form of small holders taking up collective farming of single crops or form producer companies. Crop simulation modeling is being done to understand behaviour of crops in both current and future environments. Work is being done to integrate other components like natural resources, livestock, poultry and fisheries sectors evolving a Systems Modeling approach. This helps in identifying sustainable integrated farming system models to cope of the drought situations.

The era of post genomics has ushered in with vast knowledge about the genome sequences of various crop species during recent years. It is now increasingly easier to sequence and map genomes, giving scientists access to information. Nevertheless, converting this vast information to field application has remained a bottle neck. CRIDA is developing next generation research tools which will be applied to deep probe plant function and performance, under controlled and field conditions. Under the National Initiative on Climate Resilient Agriculture (NICRA), scientists are working on high throughput precision phenol typing. Large number of germplasm lines has been collected, characterized for drought tolerance in rice, maize, pigeonpea, tomato, black gram and green gram. High throughput screening and phenol typing of these germplasm lines is being undertaken using state of the art facilities like Plant Phenomics, Rainout shelters, Temperature Gradient Chambers for drought and heat tolerance across several partner institutes under NICRA. State of the art phenol typing platform with automated non destructive imaging based scan analysis of crop growth and development is going to speed up breeding for drought and other abiotic stresses.

Dryland Developmental Schemes/Projects

After independence five year plans were started, all the five year plans gave considerable importance to the creation of additional irrigation potential in the country. When five year planning started in our country, the irrigation potential was 23 million hectares which included 10 million hectares from major and medium irrigation works and 13 million hectares from the minor irrigation works. Even after fully realizing the irrigation potential, nearly half of the cultivated area in the country will remain rainfed. These regions host bulk of the rural poor (Bantilan et al., 2006). Further, the growth in irrigated agriculture, mostly based on what is known as 'green revolution' technologies, has either slowed down or stagnated and the associated environmental costs are increasingly becoming evident. It was shown that growth in GDP originating from agriculture is much more effective in reducing poverty than the GDP growth outside agriculture. It was also observed that 'additional spending in many of the rainfed areas/dryland raises far more poor people above the poverty line than does additional investment in irrigated areas (Fan and Hazell, 2000).

Considering the observation that the green revolution has largely bypassed the fragile rainfed / dryland regions, that the livelihoods of millions of rural population continue to be dependent on dryland agriculture and also that there is a need to broaden the base of agricultural growth beyond irrigated regions and crops, it becomes imperative to take appropriate policies and measures for enhancing sustainability of agriculture in these regions. Further, the emphasis of the current economic development policy on inclusiveness also requires that the rainfed agriculture development receives due attention. After independence several programmes were started for conservation and management of natural resources in drylands/rainfed areas.

Drought Prone Areas Programme (DPAP)

It is the "earliest area development programme" launched by the Central Government in 1973-74 to tackle the special problems faced by these fragile areas which are constantly affected by severe drought conditions. In 1977-78, Desert Development Programme (DDP) was launched for hot desert areas of Rajasthan, Gujarat, Haryana and cold desert areas of Jammu & Kashmir and Himachal Pradesh. Similarly, in 1989, Integrated Watershed Development Programme (IWDP) was launched under the aegis of National Wasteland Development Board for development of wastelands on watershed basis. Common Guidelines for Watershed Development, 2008 were issued and made effective from 1.4.2008. The three watershed programmes of the Department of Land Resources namely DPAP, DDP and IWDP were consolidated during 2009 as a comprehensive programme titled 'Integrated Watershed Management Programme (IWMP) and was implemented under Common Guidelines issued by National Rainfed Area Authority. However, now this has become a part of newly launched programme titled "*Pradhan Mantri Krishi Sinchayee Yojana*" (PMKSY).

Mahatma Gandhi National Rural Employment Guarantee Act

National Rural Employment Guarantee Act later renamed as the "Mahatma Gandhi National Rural Employment Guarantee Act" (MGNREGA) is a social security measure that aims to guarantee the 'right to work'. It aims at enhancing livelihood security in rural areas by providing at least 100 days of wage employment in a financial year to every household whose adult members volunteer to do unskilled manual work. Another aim of MGNREGA is to create durable assets such as roads, canals, ponds, wells, etc. Employment is to be provided within 5 km of an applicant's residence and minimum wages are to be paid at regular interval. If work is not provided within 15 days of request, applicants are entitled to an unemployment allowance. MGNREGA is to be implemented mainly by gram panchayats (GPs). The involvement of contractors is banned. Labour-intensive tasks involving earth work like creating infrastructure for water harvesting, drought relief and flood control are preferred. Apart from providing economic security and creating rural assets, the programme is helping in protecting the environment, empowering rural women, reducing rural-urban migration and fostering social equity.

National Mission for Sustainable Agriculture (NMSA)

Conservation of natural resources in conjunction with development of rainfed agriculture holds the key to meet burgeoning demands for food grain in the country. Towards this end, National Mission for Sustainable Agriculture (NMSA) has been formulated for enhancing agricultural productivity especially in rainfed areas focusing on integrated farming, water use efficiency, soil health management and synergizing resource conservation. NMSA derives its mandate from Sustainable Agriculture Mission which is one of the eight Missions outlined under National Action Plan on Climate Change (NAPCC). The strategies and programme of actions (POA) outlined in the Mission Document, that was accorded 'in principle' approval by Prime Minister's Council on Climate Change (PMCCC) aims at promoting sustainable agriculture through a series of adaptation measures focusing on ten key dimensions encompassing Indian agriculture namely; 'Improved crop seeds, livestock and fish cultures', 'Water Use Efficiency', 'Pest Management', 'Improved Farm Practices', 'Nutrient Management', 'Agricultural insurance', 'Credit support', 'Markets', 'Access to Information' and 'Livelihood diversification'. During XII Five Year Plan, these measures are being embedded and main streamed into ongoing/proposed Missions/ Progammes/ Schemes of Dept. of Agriculture & Cooperation (DAC) through a process of restructuring and convergence. NMSA architecture has been designed by converging, consolidating and subsuming all ongoing as well as newly proposed activities/programmes related to sustainable agriculture with a special emphasis on soil & water conservation, water use efficiency, soil health management and rainfed area development. Also NMSA aims at promoting location specific improved agronomic practices through soil health management, enhanced water use efficiency, judicious use of chemicals, crop diversification, progressive adoption of integrated farming systems and approaches like crop-sericulture, agro forestry, fish farming, etc. The sub-components of NMSA are soil health management, soil health card scheme, organic farming, micro irrigation and rainfed area development

Soil Health Management

Soil health management aims at improving nutrient availability in desired limits to enhance crop productivity which is the major technological challenge for ensuring food security and sustaining rural development. Plant nutrition management is also essential to sustain and enhance crop productivity to meet the demand for food and raw materials and to maintain the quality of land and water resources. To ensure soil health, accurate in ventorization of soil resources is a prerequisite. Soil health can be improved through several site and soil-specific management options.

Soil health card scheme

The GOI has launched Soil Health Card Scheme on 19.02.2015 with an objective to issue soil health cards to farmers covering all the land holdings within a period of three years. The farmers will be covered once in every three years. As per the guidelines of GOI the sharing pattern of funds for implementation of scheme during 2014-16 was 75:25, from 2015-16 the sharing pattern of funds was revised to 50:50.

Rainfed Area Development (RAD)

Drought prone areas are characterized by inadequate and erratic rainfall coupled with high evapo-transpiration rate, eroded soils and high frequency of drought. It is necessary to provide agriculture based income generating opportunities and sustaining the rainfed agriculture through optimum utilization of natural resources and resources created through various interventions. In this context, RAD component has special significance to manage the drought. The sub-components of RAD are Integrated Farming Systems (IFS) and implementing the *in situ* soil and water conservation activities like: Contour Bunding, Graded Bunding, Gully Plugging, Nala Bunds, Terracing, Contour Trenching, etc.

Organic Farming

Promotion of organic farming is an ongoing project under RKVY and NMSA from 2013-14 and in operation under three components:

1. Area Expansion under Organic farming with capacity building through Trainings and Exposure Visits
2. Establishment of Bio fertilizer Production Units
3. Introduction of new scheme for promotion of Natural Farming

Rashtriya Krishi Vikas Yojana (RKVY)

Govt. of India launched Central Assistance Scheme i.e., *Rashtriya Krishi Vikas Yojana* (RKVY) during XI five year plan period to provide incentive to states for increasing investments in Agriculture and Allied Sectors. The RKVY funds would be provided to the States as 100% grant by the Central Government. From 2015-16 onwards these are revised with only 50% support from central and the state has to put the matching 50% budget. The components/ activities eligible for development as part of RKVY are:

- Integrated development of major food crops (for inputs like seed, production of breeder seed, seed treatment, farmers field schools, farmers training etc)
- Agriculture mechanization (individual or custom hiring basis)
- Activities for soil health management – soil health cards, micro nutrient demos, etc.
- Development of rainfed farming systems in and outside watershed areas
- IPM schemes
- Promoting extension services
- Activities for promoting horticulture production
- Animal husbandry and fisheries activities
- Study tour of farmers
- Production of organic inputs and bio-fertilizers and marketing
- Sericulture

National Food Security Mission (NFSM)

The National Food Security Mission scheme was launched by Government of India during XI Plan and continued during XII Plan. Under National Food Security Mission, Government of India has envisaged certain objectives during the XII Plan. Coarse Cereals including maize and commercial crops based cropping systems (cotton, jute and sugarcane) is part of NFSM during 2014-15. Financial allocations under rice, pulses, coarse cereals and commercial crops for the year 2015-16 are part of the mission. National Mission on Oilseeds and Oil Palm (NMOOP), MM-I for Oilseeds and MM-II for Oil Palm was merged in National Food Security

Mission scheme from 1st April 2014. MM-I on Oilseeds programme is to increase oilseed production and productivity. NMOOP had different components like farm implements and machinery, plant protection chemicals and weedicides, supply of micronutrients, bio inputs, micro irrigation, soil amendments, oilseed demonstrations and trainings.

National Horticultural Mission

A National Horticulture Mission was launched in 2005-06 as a Centrally Sponsored Scheme to promote holistic growth of the horticulture sector through an area based regionally differentiated strategies. The scheme has been subsumed as a part of Mission for Integration Development of Horticulture (MIDH) during 2014-15. National Horticulture Mission is a centrally sponsored scheme in which Government of India provided 100% assistance to the state mission during the year 2005-06 and later got revised during XI plan, the assistance from Government of India will be 85% with 15% contribution by the State Government.

- It provides assistance for Area Expansion, Rejuvenation, Post Harvest, Marketing and Processing, Human resource Development etc, which will help the all round development of horticulture in the State
- To provide holistic growth of the horticulture sector through an area based regionally differentiated strategies which include research, technology promotion, extension, post harvest management, processing and marketing, in consonance with comparative advantage of each State/region and its diverse agro-climatic feature.
- To enhance horticulture production to improve nutritional security and income support to farm households.
- To establish convergence and synergy among multiple on-going and planned programmesfor horticulture development.
- To promote, develop and disseminate technologies, through a seamless blend of traditional wisdom and modern scientific knowledge.
- To create opportunities for employment generation for skilled and unskilled persons, especially unemployed youth.

Pradhan Mantri Krishi Sinchayee Yojana

Government of India launched a programme "*Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY) in 2015 and is committed to accord high priority to water conservation and its management. PMKSY has been formulated with the vision of extending the coverage of irrigation to every farm land 'HarKhetKoPani' and improving water use efficiency 'More Crop per Drop' in a focused manner with end to end solution on source creation, distribution, management, field application and extension activities. PMKSY has been formulated amalgamating ongoing schemes, viz., Accelerated Irrigation Benefit Programme (AIBP) of the Ministry of Water Resources, River Development & Ganga Rejuvenation (MoWR, RD&GR), Integrated Watershed Management Programme (IWMP) of Department of Land Resources (DoLR) and the On Farm Water Management (OFWM) of Department of Agriculture and Cooperation, Ministry of agriculture and Farmers Welfare. In rainfed areas under this scheme the following activities are being promoted:

- Water harvesting structures to be constructed such as check dams, nala bund, farm ponds, tanks etc.
- Capacity building, entry point activities, ridge area treatment, drainage line treatment, soil and moisture conservation, nursery raising, afforestation, horticulture, pasture development, livelihood activities for the asset-less persons and production system & micro enterprises for small and marginal farmers etc.
- Effective rainfall management like field bunding, contour bunding/trenching, staggered trenching, land leveling, mulching, etc.
- Repair, restoration and renovation of water bodies; strengthening carrying capacity of traditional water sources, construction of rain water harvesting structures (Jal Sanchay);

Pradhan Mantri Fasal Bima Yojana
Crop Insurance

For the benefit of the farming community, Government has taken proactive steps and is implementing the scheme "National Crop Insurance Programme" (NCIP) comprising two components i.e., 1. Modified National Agricultural Insurance Scheme (MNAIS) 2. Weather-Based Crop Insurance Scheme (WBCIS) from kharif 2014 with many more farmer-friendly features. The scheme has been re-shaped and a now it is known as *Pradhan Mantri Fasal Bima Yojana* and was launched during January 2016 in which the burden of premium on farmer has been eased out. The premium is 2% of the sum assured for kharif crops while it is 1.5% for rabi. The rate for commercial crops like cotton and other horticultural crops is 5% of insurance sum assured. The scheme is supported by technology backstopping for timely disbursement of the claims. This is one of the best instruments for the farmers to transfer the risk associated with drought and other natural calamities.

National Innovations in Climate Resilient Agriculture (NICRA)

The ICAR launched a Network Project on Climate Change in 2004 with 15 centers which were expanded later covering 23 centers across the country. In 2011, the ICAR launched a mega project called "National Innovations in Climate Resilient Agriculture" (NICRA) with four main modules: strategic research, technology demonstration, knowledge management and capacity building. Technology demonstration was taken up in the farmer's fields in a participatory manner to make the farmers self-reliant for adaptation under changing climate. These climate resilient villages are now serving as models and also as learning sites for up-scaling and expanding to other parts of the district. Demonstration of available locations specific technologies related to natural resource management, crop production, livestock & fisheries and institutional interventions is the primary objective for enhancing adaptation gains and mitigation potential for building climate resilience. Technology demonstration component (TDC) under NICRA is being implemented in 121 vulnerable districts of the country through 121 Krishi Vigyan Kendra's (KVKs) spread across the country in 28 States and 1 Union Territory through eleven Zonal Project Directorates, now known as ATARIs. The National Agricultural Research System (NARS) in general and the institutes are addressing the research needs of rainfed agriculture and developed a number of technologies over years. These can be broadly categorized into improved crop varieties (resistant to drought or moisture stress, high yielding, resistant to pests and diseases, etc.), crop management (adjusting time of sowing, interculture, etc), resource management (off-season tillage, *in-situ* conservation, rain water harvesting practices, etc.) and nutrient and pest management technologies. Adoption of these technologies in isolation and in combination with one another has shown significant yield gains. The contribution of changes in yields over years to the changes in production reflects the contribution of technology.

Dryland Agriculture and Policy Bias

The circumstances at the time of independence rightly demanded that food production be increased considerably to meet the acute food shortages that the country was facing. The initial increases in food grain production came from the expansion of area cultivated. The real thrust to production came in the form of green revolution which was a result of the efforts of the National Agricultural Research System, investments made in irrigation infrastructure, extension efforts of the departments of agriculture of state governments, favourable policy making and more importantly the diligence of the farming community. This growth in production led by productivity gains was largely based on the use of high yielding crop varieties, intensive use of chemical fertilizers, irrigation and plant protection chemicals. Though such technology was observed to be scale-neutral, it was not neutral to access to resources and thus bypassed many farmers who do not have access to resources and many harsh environments where the access to irrigation is limited and the soils are highly degraded. And the development of HYVs for rainfed less favored areas is difficult and the adoption of such varieties is hampered by the diversity in growing conditions of these regions (Fan and Chan-kang., 2004). The process of such an agricultural development model, most of the policy making, investments and institutions for supporting agriculture was built around the requirements of the input intensive irrigated agriculture model. Most of subsidies like those on chemical fertilizers, irrigation water, institutional credit and price support largely went to the farmers growing irrigated crops and the farmers growing rainfed crops did not have such support. The policies related to procurement and public distribution system also favoured the two cereals namely rice and wheat and hence most of the benefits of such policies were enjoyed by a few states contributing to the national food grain stocks. Except the programmes related to watershed development, there is no major programme that addresses to the specific needs of rainfed agriculture in the country. The investments on watershed development are at present around Rs.12, 000/ha which is much less than what is being spent on creation of 'formal' irrigation facilities. As mentioned earlier, the very nature of dryland agriculture is highly diverse and is very different from the irrigated agriculture. The problems are variable across space and over time within a given location. The current models of agricultural extension system do not fully match with the requirements of promoting dryland agriculture. The extension system should have the capability of guiding the farmers in optimally utilizing the natural resources available in the region rather than limiting themselves to see that a few critical inputs are made available to the farmers. The research and extension systems should work in close liaison so that technologies are adapted to the local needs as a prescriptive model is least likely to work in dryland agriculture. The extension systems have to work with farmer groups rather than with individual farmers as it is not possible to have technologies and systems in place for optimum utilization of natural resources at the scale of an individual land holding.

Emerging promises

Recognizing the specific needs of dryland agriculture, there have been several attempts to address the challenges of raising productivity of rainfed agriculture in the country by a number of organizations from the government, civil society and various other organizations like international donors. What is common across such successful interventions that had a positive effect in productivity, incomes and status of natural resources is that they forged partnerships with institutions that have different strengths to be harnessed in cohesion and provided the necessary technological, institutional and capital support. Many of the interventions that are recommended for sustainable growth in rainfed agriculture revolve around soil and water conservation, integrated nutrient management, timely availability of inputs, timely farm operations, linkage to markets, etc,. Such interventions are both knowledge intensive and labour intensive and often mobilization of community around addressing the problems becomes a necessary condition. This ability to mobilize the community was also identified as one of the key contributors to the successful implementation of watershed development and livelihood projects in the country.

Research and Policy Needs in Dryland Agriculture

Dryland agriculture is synonymous with risky agriculture as production is dependent on monsoon rains known to be inadequate, erratic and undependable. The productivity levels are not only low but are also highly variable which act as an impediment to investment by the resource-poor farmers. Climatic risk is manifested in terms of incidence of droughts, floods and high intra-season variability in rainfall. Hence, risk - climatic and other forms of risk - remains a key challenge to the researchers and policy makers. A dissection of risk points to two basic factors - poor biophysical capacity of soils in terms of nutrients, organic matter, water holding capacity and low availability of water. The generic nature of these problems is more or less adequately understood and recognized. However, what and how to address these issues in varied situations is an important challenge that deserves the attention of all concerned in the short term. There has been ample evidence of beneficial effects of improving organic matter through such approaches as INM on the levels and stability of crop yields. Similarly, the potential economic benefits from rain water harvesting at farm level has been well demonstrated. Translating this evidence into wide spread adoption of the relevant practices constitutes the challenge for short and medium term.

CONCLUSION

Sustainable agriculture policy should aim at promoting technically sound, economically viable, environmentally non–degrading and socially acceptable use of country's natural resources – land, water and genetic endowments. The processes of technology development and transfer, policy making related to agriculture in general and dryland agriculture in particular and input and service delivery systems are to be made more proactive, cohesive, integrated and flexible in order to make dryland agriculture viable and sustainable. It should be recognized that the critical problems of dryland agriculture are different from those of irrigated agriculture and therefore need different solutions and hence a different approach. The approach must be able to deal with the complexity and diversity of the dryland environments. Accordingly, the solutions are bound to be location specific and replicability and scalability are not easy to ensure in dryland agriculture. Ecosystem services provided by Dryland/rainfed regions or crops should be recognized by policy making and programme formulation. Investments are to be enhanced, targeted and prioritized for diverse Dryland/ rainfed regions.

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