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50 Years of Dryland Agriculture Research in AICRPDA: An Overview

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Introduction

Dryland agriculture is as old as agriculture. Expanding the domain of dryland agriculture, currently rainfed agriculture accounts to 52 per cent (which is totally rain dependent) of the net sown area (73.3 M ha), home to two-thirds of livestock and 40% of human population and contributes 40% of food production and supports 83% of coarse cereals, 81% of pulses, 70% of oilseeds, 67% of cotton and 40% of rice. In rainfed regions, agriculture is influenced by both bio-physical and socio-economic factors and their interactions. Concerted research and development efforts in dryland agriculture date back to pre-independence period in India. In this article, an overview of dryland agriculture research in All India Coordinated Research Project for Dryland Agriculture (AICRPDA) is presented.

Historical developments in dryland research in India

Pre-independence period

The First Famine Commission was appointed in 1880 by Government of India to suggest measures to tackle drought and also to suggest preventive measures to avoid famine in future. In 1920, the Royal Commission, India, noted that "the problems of cultivation of crops in tracts entirely dependent upon rainfall deserve far closer attention". In 1923, the first systematic and scientific approach to the problem of dryland farming was started by establishing Dryland Research Station at Manjri near Pune. Subsequently, during 1933-35, the Imperial (now Indian) Council of Agricultural Research (ICAR) established five Dry Farming Research Stations at Solapur, Bijapur, Hagari, Raichur and Rohtak. The research at these stations continued up to 1943, based on which a dry land farming technology package was developed in 1944. The method of cultivation was named as Bombay Dry Farming, Madras Dry Farming and Hyderabad Dry Farming (Kanitkar, 1944, Kanitkar, 1960; Kanitkar *et. al.,* 1968) depending on the province. These dryland farming technology package mainly consisted of: i). constructing contour bunds as the basic and essential treatment, ii). occasional ploughing of lands, iii). repeated shallow cultivation of soils to remove weeds and conserve moisture during the rainy season, particularly for *rabi* (post-rainy season) sorghum, v). adding moderate quantities of farmyard manure to maintain the fertility and physical conditions of eroded land, vi). wide sowing with low seed rate, vii). repeated (4 to 5) intercultivations, viii). adopting crop rotation, wherever possible and ix). fallowing a part of the farm holding systematically every year to grow crops in alternate years. These measures increased productivity by 15-20% only over a base level of 0.2 to 0.4 t/ha and thus did not become popular (Choudhary, 1972). This was the first step to scientific crop planning as per land capability in dryland areas.

All India Coordinated Research Project for Dryland Agriculture (AICRPDA): Genesis

A Central Soil Conservation Board was established in 1953. During 1954, 8 soil conservation training and demonstration centres were established by ICAR with focus on soil conservation techniques with secondary importance to crop production. During 1963-64, with the introduction of high yielding varieties of rice, wheat, maize, and pearl millet and other enhanced use of inputs in irrigated areas, the agricultural scenario changed in the country. However, there was a wide disparity between irrigated and dryland areas necessitating completely a new effort to improve the dryland production systems. Further, the droughts of mid-sixties catalysed the Government of India to invest on dryland research significantly.

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, the Fourth Five Year Plan (1969-74) emphasized the urgent need for focusing attention on hitherto neglected farmers of the dryland 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 region and to moderate the periodic drought related adverse impact on total agricultural productivity. Further, droughts of mid-sixties catalysed the Government to invest on dryland research significantly. In 1969, the Government of India with strong aim of eradicating poverty, evinced keen interest in dryland research and development programs. In 1970 the ICAR launched the All India Coordinated Research Project for Dry land Agriculture (AICRPDA) in collaboration with the Canadian International Development Agency (CIDA) with 23 centres with co-coordinating cell at Hyderabad. The AICRPDA centres were identified based on moisture deficit index (MDI). The initial objectives of the Project were to i). Conserve soil and water and make the best use of these resources for crop production, ii). Investigate methods of increasing average per farmer yields by at least 100%, and iii). Devise means of stabilizing dryland agriculture by evolving contingency plans to meet seasonal aberrations. Tangible results were to be tested and adopted in state government pilot projects attached to each research centre.

Milestones (1970-71 to 1987)

- 1971, the 23 centres included 15 main centres and 8 sub centres. The 15 main centers were Hisar, Jodhpur, Bellary, Rajkot and Anantapur in MDI -60 to -80%; Solapur, Akola, Kovilpatti and Hyderabad in MDI - 40 to -60%; and Bangalore, Varanasi and Indore in MDI -20 to -40% and remaining 3 centres, Ranchi, Bhubaneswar and Dehradun were special problem areas. The 8 sub centres were Bijapur, Udaipur (shifted to Arjia in 1985), Ludhiana, Anand and Agra in MDI -40 to -60% and Jhansi, Rewa and Samba in MDI range of -20to -40%.
- An additional special centre was at IARI, New Delhi (MDI -40 to -60%) which was subsequently merged with coordinating cell at Hyderabad. This centre was set up primarily to cater to basic research needs in the fields of physiology and agrometeorology
- Dehradun center was discontinued in April 1985. Later on Anand was shifted to Sardarkrishinagar; Ludhiana to Hoshiarpur and then to Ballowal Saunkhri, and Samba to Rakh Dhiansar; Vijayapura and Rewa were upgraded as main centers
- In 1975, the scope of the project was enlarged to focus on transfer of technology through training of extension personnel and teachers of KVKs in innovative dryland technology
- 1976, the Operational Research concept was introduced for technology assessment, refinement and transfer. 3 ORP centres at Ranchi, Bangalore and Hoshiarpur were started.
- 1979 - ICAR launched National Agricultural Research Project (NARP) which strengthened the regional research capabilities of agricultural universities with location specific research including dryland agriculture
- In 1984, 3 ORP centres added at Anantapur, Hisar and Arjia, in 1985, at Solapur and, in 1986 at Indore
- In1985, Faizabad was added as sub centre
- 1985 - Planning Commission in view of the national need to strengthen dryland agriculture research, the Project Directorate /Main centre, Hyderabad was upgraded to Central Research Institute or Dryland Agriculture (CRIDA) in April, 1985 to undertake basic and strategic research while adaptive research continued with AICRPDA centres with coordinating cell at Hyderabad.

Initially AICRPDA's activities were supported with CIDA (Canadian International Development Agency) during 1970-1987 through a bilateral collaboration agreement the Government of India and Canada signed in 1970. In the first decade of AICRPDA (1971-81) research was on developing suitable technology required by the farming community for increasing and stabilizing crop yields in drylands.

Aligning AICRPDA research with national/states priorities in rainfed agriculture development and policy

- 1973 - Drought Prone Area Programme (DPAP)
- 1970s – ICAR Crop AICRPs-AICRPDA: Crop improvement research in developing drought tolerant varieties by various crop AICRPs
- 1974 - Integrated Dryland Development Project
- 1977 - Desert Development Programme
- 1982 - Special Programme on Integrated Watershed Management
- 1984 – ICAR Model Watershed Progarmme - 30 model watersheds (500-1000 ha) in 13 states were assigned to AICRPDA for technological backstopping.
- 1986 - With the success of model watersheds, Government of India launched National Watershed Development Programmes in Rainfed Area (NWDPRA) in 15 states
- 1987 - The performance of model watersheds came into sharp focus during drought period of 1987.

Presently, the Mandate of AICRPDA (since 2018) is:

On-station research

- To optimize the use of natural resources, i.e. rainfall, land and water, and to minimize soil and water loss and degradation of environment
- To evolve a simple technologies to increase crop productivity and viability
- To increase stability of crop production over years by providing improvements in natural resources management and crop management systems and alternate crop production technologies matching weather aberrations
- To develop alternate and sustainable land use systems; and
- To evaluate and study transferability of improved dryland technologies to farmers' fields.

On-farm research

- On-farm participatory research on rainfed integrated farming systems
- Technology assessment/refinement
- Implementation of the research findings/ doable rainfed technologies

AICRPDA - CIDA collaborative research (1970-71 to 1987)

During 1970-71 to 1987, the AICRPDA-CIDA collaborative research was in three phases i.e., 1970-75, 1976-82 and 1982-87. During this period, sound foundations of systematic and location-specific research were laid out across AICRPDA centres (IARI, 1970; Krishnamoorthy, 1971; Krishnamoorthy, 1972; Krishnamoorthy and Chowdhury. 1972; Krishnamoorthy *et. al.*, 1974; Singh, 1987; Singh and Singh, 1987).

First Phase (1970-75): The location specificity of the technology was emphasized leading to development of specific projects with the type experiments in agronomy on the concept of "Low Monetary Input", 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 focus was on four major aspects related to dryland agriculture viz. agronomy, soils, plant breeding and agricultural engineering. The significant feature of this programme was attaching each dryland research centre to the Integrated Dry Land Agriculture Development Project (IDLADP), where scientists interacted with the farmers leading to problem identification.

During early 1970s, the AICRPDA centres were initiated research on contingency crop planning and midseason correction to cope with delayed onset of monsoon, early withdrawal monsoon, intermittent dry spells of various durations, and prolonged monsoon. During 1971-72, sunflower was introduced as alternate crop at all centres. Research on rainwater harvesting continued with focus on farm ponds, storage of water in farm ponds, protective irrigation and diversification to high value crops. After 1985, horticultural crops were introduced as alternate land use systems. Poor crop establishment was the major problem with most framers using bullock power. Seed drills for bullock power were developed. Canadian seed drills were imported to ascertain whether the mechanical principles which they used could be modified for Indian conditions and adopted for bullock drawn equipment. At Centres, agricultural engineers worked in close association with agronomists to develop ferti-seed drills viz. Shivaji multipurpose tool bar (Soalpur), Malaviya seed drill (Varanasi), Birsa seed rill (Ranchi), Ridger planter (Hisar) and later Plough planter by CRIDA.

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 (Freyman, 1975; Venkatachary *et. al.*, 1979; Patel *et. al.*, 1981; Chetty, 1983; Singh and Singh, 1983; Singh *et. al.*, 2004). The significant area identified was tailoring the technology to the aberrant weather situations.

Second Phase (1976-1982): the focus on dryland research was identifying efficient methods for crop lifesaving 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.

Third Phase (1982-1987): Dryland research continued cropping systems, i.e., both intercropping and double cropping, that could ensure stable optimal yields and maximize profits in relation to agroclimatic resources, with further refinement of the systems through identification of genotypes, manipulation of sowing and harvesting dates and plant populations and fertilizer use. Pulses and oilseeds formed important components of the cropping systems research (AICRPDA, 2003). Permanent manurial trials wer initiated at 18 Centres for efficient carbon and nutrient balance and optimization (1984 onwards). These benchmark experiments are serving as platforms for intensive research on carbon sequestration, nutrient use efficiency, development of data sets for C modeling and soil quality assessment.

Initial outputs

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. Innovated in 1973, in the Alfisols of Hyderabad, sorghum + pigeonpea intercropping system (2:1) was promising in replacement series while sorghum (1.8 lakh plants/ha) + pigeonpea (75,000 plants/ha) and sorghum+ greengram (2:1) in additive series were promising. Studies on low monetary inputs like improved seed, timely sowing and timely weeding helped bridging the yield gaps in sorghum in Alfisols of Hyderabad (Singh *et. al.,* 1987). Across the AICRPDA centres, 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 anti-transpirant for controlling the transpiration losses of barley and sorghum. Under severe drought at Anantapur, the groundnut yield increased by 173 kg over 520 kg/ha with 6% kaolin spray (during the experimental period of 7 seasons, drought occurred only in 4 seasons). In moderate drought at Dantiwada, pearlmillet yielded 213 kg more over 894 kg/ha, while the calcium chloride spray (5%) increased yields by 222 kg over 894 kg/ha (during the experimental period of 6 seasons, drought occurred only in one year). In moderate drought, under semi-arid region and Inceptisols, pearlmillet showed an increase of 75 kg over 1954 kg/ha with kaolin spray. 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 (Verma, 1982). Another milestone in dryland research was refinement 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 sowing time decided the choice of crops. With the advent of high yielding and input responsive varieties to suit different situations, agriculture became more 'Production oriented' (Vijayalaxmi *et. al.* 1975; Friesen *et. al.*, 1982; Venkateswarlu, 1985; Sigh and Venkateswarlu, 1985; Singh *et. al.,* 1987; Singh *et. al*, 1988; Hegde, 1988).

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. It assisted in greater rainwater absorption and control of pernicious weeds. 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 Inceptisols. 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. Extensive tillage of sandy soils (common to desert areas) made them more vulnerable to wind erosion. Superficial scraping to eliminate weeds was found adequate. Surface mulching with crop residues like sorghum and maize stubbles, dry grass, wheat straw and pigeonpea stalk prevented moisture loss and prolonged the moisture retention period and enhanced the yields of crops (Patil *et. al.,* 1981). Year-round tillage as a means of control of weeds and to 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. Ridges and furrows always increased the yield, however with more effectiveness during moderate drought (AICRPDA, 2003). In areas with low rainfall (<70 mm), both inter-plot and intra-row water harvesting systems were recommended. In areas with 700 to 1000 mm rainfall, the first attempt is to conserve as much rainwater as possible where it falls. The work on sealants to reduce seepage in farm ponds indicated natural silting had very little practical application as this would reduce seepage space considerably. Scheduling irrigation to moisture depletion, or according to the need of the crop taking into account cumulative pan evaporation would help in increasing the efficiency of water use in post rainy season areas (Vijayalaxmi,1983). Inter-terrace land treatments like providing a bed in the form of a broad-bed and furrow and ridging resulted in higher sustainable yield. Mulching increased sustainability both in rainy and post-rainy seasons. In case of supplemental irrigation, higher sustainability in yield was obtained when the limited water was applied to post-rainy season crops (Singh *et. al*., 1990).

The research on intercropping systems (ICSs) at 23 cooperating centres of the AICRPDA during 1971 to 1981 indicated that low productivity of ICSs prior to 1970 was due to the replacement series while the work by AICRPDA suggested additive series was most successful, i.e. out of 59 experiments on replacement and additive series with base crops as sorghum, maize, pearlmillet, pigeonpea, safflower and wheat, in 54 experiments the 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 (Singh and Subba Redy,1988; Vishnumurthy and Vijayalaxmi, 1993). The performance of the ICSs was 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. Further, the ICSs over the years and across locations in India proved that *kharif* season is more favourable to intercropping than *rabi*, probably due to replenishment of soil moisture (Chetty, 1983). In ICSs, the complementarity could be increased with the staggered planting of component crops than simultaneous planting, for e.g., in Alfisols, fingermillet + pigeonpea at Bangalore and groundnut + pigeonpea at Anantapur, the productivity and profits substantially increased by one month advancing planting of pigeonpea than the other crop, however at the optimum sowing time of the base crop. 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; Rafey and Verma, 1988). In widely spaced crops like pearl millet and pigeonpea, 2:1 proportion was found to be better at several locations (Umrani *et. al*., 1992). Suitable varieties of predominant rainfed crops for weather aberrations were identified, for example, for delayed onset of monsoon, the sorghum varieties recommended were: CSH-1 at Akola; M-35-1 at Bellary; S-1049 at Dantiwada; CSH-6 at Udaipur (AICRPDA, 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 more efficient than cotton (Singh, 1987). 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 dryland research in this area clearly brought out that in the high rainfall (> 1000 mm) regions of Orissa, Eastern Uttar Pradesh and 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 Malwa (Madhya Pradesh) and 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 dryland research was the identification of the most compatible genotypes of the component crops of the system for higher system productivity.

A new concept of fertilizer use was evolved to tailor to the available soil moisture status at least in post rainy season areas. The studies conducted across AICRPDA centres 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 (Anonymous, 1977). The magnitude of response deceased with the higher rates, except for maize. Yield advantages were associated with the split application of N in cereals. Application of inorganic and organic fertilizers in set furrows in groundnut, pearlmillet and cotton (Saurashtra) gave better yields.

The sustainability analysis of the practices developed for increasing productivity of dryland crops is an aspect distinctly different from productivity. In dryland research, methods of soil and water conservation have been regarded as a pre-requisite to providing better crop growing environment. Other practices like optimum plant density, appropriate cropping system and fertilizer use have been found to be the key factors in increasing the productivity of dryland crops. Although these aspects have been documented in terms of their relative importance for increasing productivity, the sustainability aspect did not figure anywhere. Sustainability is directly linked with the minimum guarantee that a given practice can hold in terms of productivity and profitability. In case of plant density, the average productivity over varying plant densities are 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.

In most of the situations, the sustainability of yield was higher when the recommended dose of fertilizer was applied. In case of cereals, higher sustainability was obtained when the recommended dose of nutrients was applied through chemical sources. In the case of oilseeds, however, the recommended dose applied half through chemical fertilizer and other half through organic source led to higher sustainability values. Available nitrogen, organic carbon and phosphorous 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, phosphorous and organic carbon. Green leaf manuring proved promising in increasing the sustainability in yield and improving the organic carbon, infiltration rate and hydraulic conductivity of the soil (Singh *et. al.,* 1990).

The experiments on alternate land use systems (ALUS) for arable and marginal lands were initiated at AICRPDA in 1981. Though the work on alley cropping was in progress since 1981 at AICRPDA, it became a core project of AICRPDA programme only in 1985 when 10 centres initiated this work. *Leucaena lecocephala* 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 (*Stylosanthes hamata* with sorghum rotation), silivipasture (*Leucaena leucocephala* + *Stylosanthes hamata* + *Cenchrus ciliaris*) agri-horticulture (guava/custard apple/pomegranate/ber based) (Korwar *et. al.*, 1997; Singh *et. al*., 1987). *Leucaena leucocephala* is the most popular tree species to serve as hedgerow in the alley cropping system (Hegde *et. al.,* 1988). Studies at AICRPDA during 1975-1983, revealed that *Dicanthium, Sehima* and *Lasiurus* are suitable for severe drought prone areas while *Cenchrus ciliaris*, *Panicum maximum* and *Urochloa* were for moderate drought prone areas. *Stylosanthus hamata,* a pasture legume, was identified for improvement of soil fertility and as quality fodder for Alfisols of Hyderabad (Reddy and Hampaiah, 1982)

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 centres 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. Agronomists at the centres at Solapur, Bijapur, and Hyderabad worked on these aspects and developed contingent crop planning strategies for delayed on set monsoon (AICRPDA, 1983a). The efforts made by the agronomists in this scarcity region by introduction of safflower as a sole crop in scarcity zone of Maharashtra ultimately augmented the oilseed production, further, at Indore safflower was introduced in rotation with soybean which gave a yield of 2 t/ha with residual moisture. In Bhubaneswar region, groundnut was introduced as a *rabi* crop. 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 in Indian Farming, 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" (AICRPDA, 1983b). Another significant outcome of dryland research in dry land farming was, in 1979, the AICRPDA was the first to bring out "Improved Agronomic Practices for Dry land Crops in India" with the recommendations on the soil type-wise crops and varieties, contingent crop planning, suitable cropping systems and other agronomic practices. The concept and contents were well received and emulated by other AICRPs. The contributions of ORPs in demonstration of dry land technologies, action research and feedback on technologies was immense which helped in refining technologies related to *in situ* moisture conservation practices, cropping systems, etc. (Singh *et. al.,* 1987).

Watershed approach for dryland agriculture development

The soil and water conservation technologies emanated from the project could contribute to design and implement Integrated Dryland Agriculture Development (IDLAD) project during 1971-1981 in various states. The project through adoption of 30 model watersheds (1983-87) clearly established that a permanent solution to the problems of chronically drought affected areas through overall development of the water and land resources. Further, productivity gains in these watersheds indicated two to several fold increase in crop productivity; rise in income through profits and improvement in cropped area and cropping intensity and a concomitant rise in number of working days with overall potential in improving and stabilizing the productivity of drylands. Above all it stimulated the concept of development of rainfed agriculture with watershed as the unit of activity. Based on the experiences of these model watersheds, Government of India launched National Watershed Development Programmes in Rainfed Area (NWDPRA) in 1986 in 15 states. Launching of NWDPRA has its roots in the successes witnessed through model watershed programme and a vital aspect of this massive national effort in stabilising and improving the quality of agriculture in rainfed areas.

Initial experiences gained

Early research efforts in AICRPDA during 1970s and 1980s helped in identifying potential production through a combination of simple agronomic techniques such as off-season tillage and contour farming to enhance *in situ* water conservation, improved biotypes of crops, soil fertility management to overcome nutritional constraints, and weed control to avoid non-productive use of soil stored moisture and nutrients. The research also provided feedback for further refinement of the production agronomy techniques, cropping systems and rainwater-management methods. By adjusting row ratios of crops of an intercropping system to minimize competition, the traditional mixed cropping system was upgraded in productivity.

Compared to earlier efforts, it was clearly recognized that to bring about stability and improvement in rainfed agriculture, it was essential to apply the techniques of rainwater conservation and standard agronomic practices in an integrated mode. With this approach the productivity of rainfed crops rose by a factor of 2 to 3. More importantly, despite aberrations in year-to-year rainfall behaviour, occurrence of total crop failure could be eliminated. Applicability of new research findings was tested in the farmers' fields with promising results. However, the sustainability of various farming techniques under farmer's situation was non-commensurate with the benefits demonstrated at the research farm. A major emphasis of the technology application was aimed at arable farming. As a result, the application ignored the capability of land to support various farming enterprises and did not integrate the development of non-arable areas with arable areas. Nearly one half of the lands in rainfed areas do not qualify to be devoted to arable farming based upon the land capability classification criteria. Collection of runoff in farm ponds was not widely accepted because the cost of seepage proofing, a necessary investment for high-percolating Alfisols, was not affordable to a majority of the small and marginal farmers. Apart from problems of seepage and high initial investment in constructing individual farm ponds, water lifting and method of irrigation of limited amounts of harvested water remained crucial aspects of adoption.

Keeping in view the above constraints, the research efforts were reoriented during the 1980s. It was recognized that water deficits in a natural body, such as land, is a reflection of imbalance in the hydrological cycle on a micro-scale. The effective conservation of rainwater and its management and budgeting led to the emergence of a watershed concept which integrates the development of arable and non-arable areas. Since conduct of rainwater in one area influences its availability in the adjacent area, with watershed as the basic unit of activity it became possible to craft comprehensive research approach for an efficient natural resource use plan. In 1983, ICAR piloted a National Watershed Programme with 47 model watersheds spread across the country. AICRPDA was bestowed with the responsibility of backstopping the activities of 30 model watersheds in 13 states. Compared to earlier programmes, the entire strategy framework was holistic in that it combined the technologies relating to soil and water conservation with the standard agronomic practices against the backdrop of alternative land uses. Furthermore, these watersheds served as testing grounds for the already available technologies. The impact at Nartora, Tejpura, Mittemari received the National Productivity Awards for excellence. Significant gains in terms of productivity, groundwater recharge and cropping intensity could be observed at several watersheds.

A modest beginning on adoption of improved technologies was observed as early as in 1970s. This resulted in corresponding improvement in the productivity of rained crops like sorghum, pearlmillet, groundnut and cotton are a testimony to this act. During 1981-93, area under coarse cereals put together (rained area 91%) had fallen by 17 Mha. Despite this marked fall in area, the production increased by 6 million tonnes. This indicated a positive impact of research activities and then interfacing with development efforts.

The soil and water conservation technologies emanated from the project could contribute to design and implement Integrated Dryland Agriculture Development (IDLAD) project during 1971-1981 in various states. The project through adoption of 30 model watersheds (1983-87) clearly established that a permanent solution to the problems of chronically drought affected areas through overall development of the water and land resources. Further, with productivity gains in these watersheds indicated two to several fold increase in crop productivity; rise in income through profits and improvement in cropped area and cropping intensity and a concomitant rise in number of working days with overall potential in improving and stabilizing the productivity of drylands. Above all it stimulated the concept of development of rainfed agriculture with watershed as the unit of activity. Launching of NWDPRA has its roots in the successes witnessed through model watershed programme and a vital aspect of this massive national effort in stabilising and improving the quality of agriculture in rainfed areas.

Dryland agriculture research in AICRPDA - Post 1987

The research prioritization in AICRPDA, to the larger extent, has been in tune with the emerging problems in dryland agriculture in the country and in tune with the ICAR prioritized programmes/goals. AICRPDA provided a platform in dryland agriculture research and development network at national level to address the emerging challenges in dryland agriculture from time to time in a concerted and coordinated manner while maintaining the location specificity of the research.

Milestones – Post 1987

- 1996, Bhubaneswar centre was shifted to Phulbani.
- In 2005, three more main centers were started at Jagdalpur (IGKV), Chattisgarh, Jorhat (AAU), Assam and Parbhani (VNMKV), Maharashtra.
- In 2010, Jorhat and Ranchi centres were shifted to Biswnath Chariali and Chianki, respectively.
- In 2016, during XII Plan, five more new voluntary centres were started at Darsi (ANGRAU, Andhra Pradesh), Aklera (Agricultural University, Kota, Rajasthan), Munger (BAU, Sabour, Bihar), Raichur (UAS, Raichur, Karnataka), and Imphal (CAU, Manipur).
- Strengthened inter-institutional collaborative research in AICRPDA at common centres of AICRPDA and other AICRPs & ICAR Institutes across Subject Matter Divisions (NRM, Crop Sciences, Horticulture and Agricultural Engineering) of ICAR.
- AICRP on Cotton and CICR, Nagpur and 4 AICRPDA centres viz., Parbhani, Akola, Rajkot and Kovilpatti) for evaluation of high density planting system (HDPS) of cotton in diverse rainfed agro-ecologies; AICRP on Agrometeorology & CRIDA and 7 common centres of AICRPDA-AICRPAM centres on " measuring, monitoring and management of dry spells in major rainfed crop(s); AICRP on Agroforestry and CAFRI, Jhansi and. 12 AICRPDA centres for quality agroforestry research; AICRP on Forage Crops and IGFRI, Jhansi and 6 AICRPDA centres for quality research in forage crops at common centres; AICRP on Integrated Farming Systems and IIFSR, Modipuram and 5 AICRPDA centres for strengthening rainfed integrated farming research; AICRP on Fruit Crops and 5 AICRPDA centres for quality research in fruit crops at common centres); AICRP on Farm Machinery- for technical backstopping and capacity building
- In 2018, during SFC 2017-20, a new voluntary centre was initiated at Adilabad, PJTSAU
- In 2018, 8 ORP centres were closed at Anantapur, Arjia, Ballowal Saunkhri, Bengaluru, Chianki, Hisar, Indore and Solapur

Expanding the rainfed research base in the AICRPDA Centre's domain ACZ

- To address the rainfed agriculture problems in diverse agro-ecologies and production systems in the domain ACZ of each centre, since, 2019-20, thematic experiments were initiated at 16 Agricultural Research Stations and 2 KVKs viz. RARS, North Lakhimpur (Biswanath Chariali), ARS, Kanker (Jagdalpur),RRTTS, G. Udayagiri (Phulbani), Rajiv Gandhi South Campus, Barkachha (Varanasi), ARS, Udaipur (Arjia),KVK, Pathankot (Ballowal Saunkhri), Maize Research Centre, Udhampur (Rakh Dhiansar),ARS, Balijigapade (Bengaluru),RRS, Bawal (Hisar),RRS, Radhanpur (SK Nagar),ARS, Annigeri (Vijayapura), ARS, Mohol (Solapur), KVK, Dewas (Indore), RARS, Nandyal (Anantapuramu), Cotton Research Station, Kukda (Rajkot), ARS, Buldana (Akola), Red Soil Farm, Velayuthapuram (Kovilpatti), Bajara Research Station, Vaijapur (Parbhani).
- In 2018, a new functional mechanism of On-Farm Research (OFR) was initiated at all 22 centres in AICRPDA. The focus is on two aspects i.e. technology assessment refinement and upscaling and on-farm participatory rainfed integrated farming systems research
- At present, the AICRPDA network has 18 main centres, one sub centre, and 9 voluntary centres including 3 voluntary centres at IGFRI, Jhansi, CAZRI, Jodhpur and Bellary centre of IISWC, Dehradun
- **Aligning AICRPDA research with national/states priorities in rainfed agriculture development and policy**
- Some national and state programmes/schemes are listed below.
- Integrated Watershed Management Programme (1990s)
- Taming the droughts: Drought coping measures during the moderate and severe droughts/deficit rainfall experienced in 1992,2000, 2013, 2014 and 2015 in various parts of the country.
- ISOPOM-ICRISAT-Project- Farmer- Participatory Groundnut Improvement in Rainfed Cropping Systems (2006)
- Livelihood Security in Hoshiarpur District of Punjab (2008)
- Rashtriya Krishi Vikas Yojana (RKVY) (Since 2015)
- National Rural Livelihood Mission (NRLM),
- National Food Security Mission (NFSM) (Since 2014)
- Prime Minister Krishi Sinchayee Yojana (PMKSY)
- National Mission on Sustainable Agriculture (NMSA) (2015)
- Revision of Drought Manual, MoAFW, GoI (2016)
- Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS)
- Prioritization of Rainfed Area for Developmental Planning - National Rainfed Area Authority (NRAA), MoAFW, GoI (2020)
- Revision of Common Guidelines for New Generation Watersheds, National Rainfed Area Authority (NRAA), MoAFW, GoI and MoRD, GoI (2020)
- National Agriculture Disaster Management Plan (NADMP), MoAFW, GoI and MoHA, GoI (2021)
- District Agriculture Contingency Plans for 650 districts, MoAFW, GoI (2011 onwards)
- Drought Proofing Action Plans, MoAFW, GoI for 24 districts (16 in Karnataka and 4 each in Rajasthan and Andhra Pradesh) (2017)
- Boochetana, Govt. of Karnataka
- Panta Sanjeevani, Govt. of Andhra Pradesh
- Krishi Bhagya Scheme, Govt. of Karnataka
- Farm pond/percolation tanks (Balram Talab and Lakhan Talab schemes) in Madhya Pradesh
- Dryland Farming Mission, Govt. of Maharashtra
- Dryland Farming Mission, Govt. of Karnataka
- Nanaji Deshmukh Project on Climate Resilient Agriculture (PoCRA), Govt. of Maharashtra (2017)
- Comprehensive District Agriculture/Land Development Plans of various districts
- Identification of farming systems modules for small and marginal farmers of southern Rajasthan (ILRI, ATMA)
- Soil test based P recommendations in groundnut growing regions of Andhra Pradesh
- RKVY - Strengthening and Promotion of Rainwater Management Activities for the Enhancing the Productivity in Rainfed Area of Mewar Region Innovations in Research (2016)
- DST - Integrated approaches to conserve the natural resources for sustainable development & to mitigate the effect of climate change in participatory mode in Kandi region, Punjab (2015)
- DST - Revival of village ponds through Scientific interventions in Kandi region, Punjab (2017)
- RKVY - Development and Popularization of Integrated Farming System Model for Rainfed Ecosystem in Northern Gujarat (2019)

Innovations in prioritization of research in AICRPDA

A unique and innovative approach for research prioritization and technical programme development was initiated since 2001 in AICRPDA by conducting: i) Brainstorming sessions, ii). Production systems-wise National Group Meetings and iii). Stakeholder Consultation Workshops, in 2001, 2008 and 2013, respectively. During these meetings/workshops the participants were farmers, scientists from CRIDA, SAUs, AICRPs, ICAR Institutes and KVKs, officials from ATMA, state line departments and NGOs. These meetings/workshops were conducted for stocktaking of the status and aspirations of the stakeholders under different land classes with farmers, link departments, research organizations, non-governmental organizations and other participants in the system at all Centers for the first time in the history of Project. The above meetings were conducted after a series of brainstorming meetings conducted by the individual centers with the stakeholders at their respective locations to draw the perspective plan of the centre. During stakeholder consultation workshops were held on emerging problems in dryland agriculture to integrate into technical programme of the centre and convergence mechanisms for technology upscaling. The Strengths, Weaknesses, Opportunities and Threats (SWOTs) are derived. The current status on rainfed agriculture viz. crops, natural resources etc., were analysed. Then the ongoing Technical Program was examined along with the scientists of the centre to analyse the gaps. New programs are formulated or treatments in the present program are augmented to fulfil expected needs within the natural resource environs for implementation. The research collaboration at centres so far has been with CRIDA, AICRPAM and other AICRPs in NRM, Crop sciences, Horticulture and Agriculture Engineering Divisions of ICAR for implementing the core research programmes either Institute or externally funded national/international/ state funded projects, some also include consultancy projects. These projects supported in meeting the objectives of AICRPDA, particularly in thrust areas of rainwater management, evaluation of germplasm, nutrient management, soil quality, carbon sequestration, conservation agriculture, climate resilient agriculture, and also for technology assessment, refinement and upscaling.

Research focus and collaboration

- **Resource conservation (soil and water conservation/ watershed):** Karnataka State Council for Science and Technology - Establishing vegetation under highly eroded conditions (1990); KSDA, Government of Karnataka - Impact of soil and water conservation measures in model micro-watershed at Yarnal (1984); US-India - Soil Conservation and Watershed Management (1990); ACIAR - Tools and indicators for planning sustainable soil management in semi arid forms and management (1996); Asian Development Bank - Improving management of natural resources for sustainable rainfed agriculture (1999); DST- Behaviour and Pattern of gully erosion in foothills of lower Shiwaliks and their management (2003) ; ISRO, GoI- Remote sensing for runoff modelling in watersheds of Dhar district, Madhya Pradesh (2003); ICAR-AP Cess-Rain water management through economically feasible water harvesting tank (2005); RKVY - Improving the productivity of dryland crops through integrated watershed approach and precision farming (2007); ICAR-USA-On Farm Water management for rainfed agriculture on benchmark watersheds in diverse eco-regions of India (2007); ICAR-National Fellow- Assessment of Sustainability of Treated/ Developed Watersheds in Rainfed Agro-Eco-Sub Regions of Peninsular India using GIS and Remote Sensing (2009); ACIAR-Impact of meso-scale watershed development in Andhra Pradesh (India) and comparative catchments in Australia Soil and water conservation (2011); ICAR- Advanced Research and Upscaling of Dryland Technologies in Northern Dry zone of Karnataka (2012);ICRISAT-CRP-Dryland systems- (2012)
- **Rainwater management***:* Germany - Artificial recharge of groundwater through integrated sand filter well injection technique (1999); DST- Assessment of improved irrigation scheduling using hydrodynamic modelling (2013); DBT- Bio-fustigation and bio-irrigation for sustaining productivity of finger millet and pigeonpea intercropping system (2016) [ICAR-CRP - Development and management of integrated water resources in different Agro-ecological region of India (2016)
- **Nutrient management:** Permanent Manurial Trials at 18 Centres – for efficient carbon and nutrient balance and optimization. These benchmark experiments serving as platforms for intensive research on carbon sequestration, nutrient use efficiency, development of data sets for C modeling, soil quality assessment; In 2000, long term experiments on tillage and nutrient management for developing conservation tillage strategies in rainfed agriculture. These experiments laid sound foundation for soil quality research in 2005, and further to Conservation agriculture in 2015; INM, SSNM, Balanced nutrition experiments were initiated to address multiple nutrient stresses in diverse soil types in rainfed production systems
- **Soil quality:** ICAR- Integrated nutrient supply and management for *rabi* sorghum under dryland condition (1997);ACIAR- Indicators and soil management options for sustainable agriculture under rainfed situation of Anantapur (1997); ICAR-AP Cess - Fertility management for soybean based cropping sequences (2000); ICAR-AP Cess - Assessing soil quality key indicators for development of soil

quality index under predominant management practices in rainfed agroecology (2005); ICAR-AMASS-Application of micro-organisms in agriculture and allied sectors (Nutrient Management, PGPR) (2006); ICAR- Crop yield and quality soil properties and economic returns under organic management in rainfed agro-ecosystem (2009); Farmers Participatory Action Research Programme - MoWR, GoI-Tank silt as an organic amendment for improving soil and water productivity(2011)

- **Cropping systems:** ICAR- National Agriculture Technology Project (NATP)-CRIDA-AICRPDA: Production systems Research in Rainfed Agroecosystems (2000); ICAR-NATP-Identification of Research Gapes in Intercropping System under Rainfed Conditions of India (2000); DFID Indo-UK Collaborative Project on Oilseed Crops Phase-II (2003)
- **Crop improvement:** CSIR-NOVOD-National Network project on integrated development of Jatropha and Pongamia (2004); NOVOD-Genetic improvement of Jatropha for oil yield and adaptability (2005)
- **Farm mechanization:** Indo-US-Research in Mechanization of Dryland Agriculture (Plan) (1997); NATP-Mission Mode Project on Dryland Farm Mechanization (2002).
- **Climate resilient agriculture:** MPCoST- Impact of Climate Change on Agricultural Crops (2008); NICRA-Developing Adaptation and mitigation strategies to cope with climate change /variability (since 2011); NICRA-Real-time contingency planning for managing weather aberrations at 23 centres (2011).
- **Conservation agriculture in rainfed production systems:** ICAR-CRP project on conservation agriculture in rainfed production systems (since 2015).
- **Nanotechnology:** Nanoparticles for enhancing water and nutrient use efficiency: ICAR-EM-Innovative nano-clay polymer composite for higher water productivity in rainfed production system (since 2015).
- **Soil carbon sequestration in rainfed production systems:** ICAR-AP Cess- Organic Carbon Assessment and its maintenance under rainfed production systems (2004); DST- - Evaluation of carbon sequestration ability plantation crops in Bastar region of Chhattisgarh (2013); DST-Carbon sequestration potential of reduced tillage system under rainfed conditions (2009)
- **GHG emission studies:** DST - Crop residue management for enhancing soil quality, crop productivity and mitigation of climate change (2012); DST -Quantifying Green House Gas (GHG) emissions in rainfed production systems (2012)
- **Rainfed farming systems research:** ICAR-AP Cess -Sustainable farming system models for marginal and small farmers of Malwa & Nimar regions of Western parts of Madhya Pradesh (2005); Enhancing fodder and milk production in Dhuwala & Gynagarh watershed of Bhilwara (2007)
- **Agroforestry systems /alternate land use:** ICAR-NATP-Development of Agri-horticulture and Agro-forestry system in Sorghum Area Decreasing Region for Overall Sustainability of Rainfed Production System in Sangli district (2000); NATP-Mission Mode Project on Land Use Planning for Management of Agricultural Resources-Rainfed Agroecosystem (2002); NABARD- Prospects of Land Use Diversification Opportunities in distressed districts of Telangana Region (2009). During 1900s, the focus was on *Zyziphus mauritiana, Annoa squamosa, Tamarindus indicus, Azadirachta indica, Dalbergia sisso* and *Grewia optiva* based agroforestry systems, during 2000s, the focus was on *Emblica officinalis, Moringa oleifera, Mangifera indica* based agri-hortisystems and since 2011 onwards, the focus has been on *Casuarina equistifolia, Melia dubia, Bambusa vulgaris, Gmeliana arborea* based agroforestry systems
- **Action research for technology refinement/ assessment/ upscaling**: Capacity building of ORPs in Rainfed Agroecosystem - An Action Research Project (2004); Farmers Part
- **Livelihood improvement:** DFID -Enabling rural poor for better livelihoods through Natural Resources Management in SAT India (2003); ICAR-NAIP-Sustainable Rural Livelihoods through enhanced farming systems productivity and efficient support systems in rainfed areas (2007); ICAR-NAIP -Enabling small stakeholders to improve livelihoods and benefits from carbon finance (2009); ICAR-NAIP-Policy and Institutional Options for Inclusive Agricultural Growth (2009); MPUAT-Livelihoods under climate variability and change: strengthening the adaptive capacity of rural poor to water scarcity in drylands (2011).

Significant research outputs

The Centres developed agro-ecology specific doable dryland technologies in various thematic areas (Padmani *et. al.*, 2009; Venkateswarlu *et. al.,* 2009; Jawahar *et. al.,* 2014; Kadma *et. al.,* 2014; Ramachandrappa *et. al.*, 2014; Sharma *et. al.*, 2015; Bastia *et. al.*, 2018; Shirahatti *et. al.*, 2018; Singh *et. al.*, 2019; Pradhan *et. al.*, 2020; *Ravindra Chary et. al.*, 2022).

Resource characterization

- Characterized changing rainfall pattern (1900-2000) in the domain AICRPDA network centres with indicated.
- Delineated 132 sub-soil groups with 41 diverse land uses in 5428 ha area in 16 microwatersheds across the country.
- Identification of the length of the effective crop-growing season in different agro-climatic regions

- **Delineation of drought-prone areas and predictions on nature and extent of their spread:** drought regions identified viz. DR-I: Chronic Drought in Arid Marginal Rainy Season Aridisols); DR-II: Chronic Drought Region in 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 Drought in Dry Semi-arid Post Rainy Season Vertic/ Vertisols); DR-V: Ephemeral Drought in Wet Semi-arid Rainy Season Vertisols/ Alfisols) ; DR-VI: Apparent Drought in Dry Sub-humid Alfisols/ Oxisols Regions) (Vittal *et. al.*, 2003; Ravindra Chary *et. al.*, 2010)
- Characterized rainwater harvesting of potential zones in the agroclimatic domains of AICRPDA centres
- Developed rainfall intensity, duration and frequency (IDF) curves for specific rainfed agroecoliogies
- **Identified emerging nutrient deficiencies in rainfed production systems:** Soils of 19 out of 21 centres had low in organic carbon (< 0.5%); available N was low in most of the soils except surface soils of Indore and Ranchi; low to very high P, available K and S varied from low to high; available Zn was below critical limit; deficient in available Ca (< 1.5 me/100 g), Mg deficient (<1.0 me/100 g) observed at many centres. Out of 21 locations, 11 are boron deficient. Studies have established that 50% of recommended N through organic sources and 50% of N through inorganic sources along with micronutrients and biofertilizers augmented overall nutrient turnovers for soil fertility management. Green manure could meet half the N requirements of a crop. Inclusion of legumes in a rotation produced benefit to the succeeding crop equivalent to 10-30 kg N ha^{-1}.
- Delineation of the potential areas suitable for mono-cropping, intercropping and double cropping across the dry farming zones of the country
- **Yield gap analysis:** Done for predominant rainfed crops in 170 rainfed districts based on the matrix of yield gap and runoff surplus index, district-based recommendations for cereals, oilseeds, pulses and cotton were made and published
- **Delineated agroforestry zones:** based on Land capability and for higher land productivity**.**
- **Delineated rainfed agro–economic zones:** For developing agri-entrepreneurships network with crop diversification and value addition in rainfed regions
- **Developed sustainability yield index (SYI):** As a measuring index for rating and selection of treatment interventions in rainfed areas. The SYI for a treatment to be rated highly sustainable was worked out to be >0.67, moderately sustainable (0.33-0.67) and low sustainable (<0.33)
- **Identified multi-nutrient deficiencies in rainfed soils:** Besides, NPK, deficiency of S, Mg, and Ca, ZN, B, Fe are identified in rained soils.

Rainwater management

Rainwater harvesting and utilization to annual crops and fruit crops proved to be beneficial (Radder *et. al.,* 1995). 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 (Havanagi, 1982). 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. At Agra, the protective irrigation increased the yield by 696 from 633 kg/ha in pearlmillet. During the experimental period of 7 seasons, the drought occurred only in 3 seasons at Agra. In moderate drought at Varanasi, the protective irrigation to rice increased yields by 320 over 1190 kg ha^{-1}. During the experimental period of 7 seasons' drought occurred in 3 seasons at Varanasi. One supplemental irrigation gave an advantage usually to the tune of 200 kg grain ha^1 cm^1 water applied. Response was mostly noted in crops to supplemental irrigation after withdrawal of monsoon (Vittal *et. al.* 2005). 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 fingermillet 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). The best that can be done in terminal drought is to irrigate the crop.

- Developed location specific in situ moisture conservation practices for diverse rainfed agro- ecologies i.e. rainfall (< 500 mm to > 1500 mm) and soil types (Entisols, Inceptisols, Vertisols, Alfisols, Aridisols) viz. deep tillage, compartmental bunding, inter-plot rainwater harvesting techniques, conservation furrow, broad bed & furrows, raised bed & furrow system, ridges & furrows, tied ridges, zing terracing, mulching techniques etc. (Katama Reddy et. al.,1992; Yellamanda Reddy,1994; Guled et. al., 2003).
- ***Ex-situ* rainwater management:** At centres, based on catchment-storage-command area relationship, standardized rainwater harvesting structures viz. farm pond and other water harvesting structures for diverse rainfall and soil types and efficient rainwater utilization for higher water productivity (Shirahatti *et. al.*, 2019; Balyan *et. al.*, 2022; Water resource thus developed could be used for life saving irrigation, extension of cropping season, increasing

cropping intensity and raising of high-value cash crops. The advantages of supplemental irrigation from harvested rainwater were significant and considerable improvement in crop yields (25-45%) was recorded at AICRPDA centres. Efforts were made for Packaging farm pond technology with standard farm pond sizes, lining with single and combination of environmentally friendly low cost materials, to reduce seepage losses, water lifting with energy efficient lifting pumps, reducing evaporation losses, and efficient water utilization through micro-irrigation systems

- Developed location-specific open well and bore well recharge models at Parbhani, Vijayapura, Bangalore, Jagdalpur and Rajkot centres with efficient filtering mechanisms

Cropping systems

The research on crops and cropping systems was focused on evaluation of the most efficient crops and their varieties for each agroclimatic location. Systematic designs were developed and improved to suit dry land conditions for evaluation of intercropping. Standard agronomic practices were worked out for important food crops. 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 underexploited crops such as horsegram 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 (Ravindra Chary *et. al.*, 2012).

- Developed efficient and risk resilient and productive intercropping/strip cropping systems for diverse rainfed agro-ecologies i.e. rainfall (<500 mm to > 1500 mm) and soil types (Entisols, Inceptisols, Vertisols, Alfisols, Aridisols). In the late 1980s and 1990s, intercropping of vegetables (okra, radish, chillies etc.) with grain crops (pigeonpea etc.) for higher income was pursued vigorously in some AICRPDA centres (Phulbani, Varanasi etc.) (AICRPDA,2003; Shankar *et. al.*, 2001; Surakod *et. al.*, 2016). Further, the additive series in intercropping systems was found to be most successful with base crops as sorghum, maize, pearlmillet, pigeonpea, safflower and wheat, with higher LERs (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. In ICSs, the complementarity could be increased with the staggered planting of component crops than simultaneous planting. Pigeonpea had been found to be unique and highly preferred component crop across production systems (AICRPDA, 2003; Itnal *et. al.,*1994). Sorghum+pigeonpea was the most preferred ICS followed by upland rice/groundnut/sorghum+pigeonpea. Overall, the best base crops appeared to be upland rice, sorghum and pigeonpea, while pigeonpea, greengram and soybean were the best component crops.
- **Developed double cropping systems for high rainfall zones:** 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 Varanasi, 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%). In high rainfall (> 1000 mm) regions of Odisha, Eastern Uttar Pradesh and Madhya Pradesh, a second crop could be grown in the residual moisture after a 90-day duration variety of upland rice than 120 days duration, similarly in the Vertisols of Malwa (Madhya Pradesh) and Vidarbha (Maharashtra), a change of 140 or 150 days sorghum 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
- Developed strip cropping systems amenable to mechanization viz. maize (grain) with 2/3 area + maize (fodder) with 1/3 area (Semiarid Vertisols, Arjia); maize (6 m strip) +blackgram (2.4 m strip) (subhumid Inceptisols, Ballowal Saunkhri); soybean + pigeonpea cropping with strips of 18.9 m each (18 & 12 rows/strip) (semiarid Vertisols, Parbhani).

Crop diversification

Based on the research information for the past 40 years across AICRPDA, 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). Diversification with nutri-cereals in rainfed agroecologies : at Kovilpatti, in post-monsoon semiarid Alfisols, intercropping of medium duration pigeonpea (Co(Rg)7) with nutricereals in 2: 6 ratio, i.e. barnyard millet (CO 2)/ foxtail millet (CO 7)/ kodo millet (Paiyur 1)/ proso millet (CO 5)/ little millet (CO 5) and pearlmillet (CO 10); in bimodal rainfall zone, at Darsi, foxtail millet- cowpea/blackgram; pearlmillet-greengram/cowpea/backgram and pigeonpea+-foxtail millet (1:5)/pearlmillet (1:2), foxtail millet-greengram; at Phulbani, finger millet (5 rows) in sunken bed + okra (2 rows).

Contingency crop planning

The rainfall data at 23 AICRPDA locations in the country were analysed with regards to: a) the dates of onset and termination of the rainy season and its variability, and b) the distribution of rainfall within the rainy season. The information so generated was fitted the selection of efficient crops, varieties, and cropping systems. Later, the agro-climatological studies helped the dryland research workers: i). to identify suitable crops and varieties for early, normal and late commencement of sowing rains, ii). to identify and match intercropping systems with the rainfall pattern), iii). determine optimum sowing periods for different crops and cropping systems, and iv). to assess the amounts of inevitable runoff available for water harvesting and recycling in arid, semiarid and sub-humid regions of the country. Weekly water balance computations were carried out to determine the water availability periods for crop growth, based on which, suitable cropping systems (mono, inter and double cropping) have been identified. The drought vulnerability of rainfed crops was assessed reflecting dates of commencement of rainy seasons, and threshold values of moisture availability for obtaining above average yields were obtained. In order to explain the patterns of rainfed crops in relation to various dates of commencement of the rainy season, crop-weather models were developed using the concept of water requirement satisfaction of the crop during its growth cycle. The probability of occurrence of different amounts of rainfall and the corresponding length of the growing season, as related to the annual rainfall could be taken as a criterion for stabilizing crop production in any region (Singh and Ramakrishna, 1993).

Based on significant work during past 50 years, the long-term strategic approaches were developed to efficiently conserve and utilize rainwater on the one hand and in-season tactical approaches to mitigate the adverse effects of weather aberrations with specific management strategies. Research in this area refined or developed several crop contingency plans specific to agro climatic zones, districts or even at micro level considering rainfall variability, soil types and dominant cropping patterns, to mitigate the drought effects to a certain extent (Singh and Ramana Rao 1988). The dryland research efforts in AICRPDA could be able to generate crop contingency plans for a dry land centre's domain (Subba Reddy *et. al.,* 2008). Further, during 2009-10, agronomists at AICRPDA centres identified crop wise contingency plans for the respective domain areas considering the weather aberrations, seasons, and predominant *kharif* and *rabi* crops with appropriate crop management strategies. Since, 2010, CRIDA has been working on district level contingency plans for weather aberrations particularly drought, addressing crops, livestock, fisheries. The farming situation and dominant cropping system wise soil and crop management strategies are given for the delayed onset of monsoon (2/4/6/8 weeks' delay) and also for in season drought (early, mid and terminal) (Venkateswarlu *et. al.,* 2011).

Under National Initiative on Climate Resilient Agriculture (NICRA), since 2011, initiated both on-station research and on-farm demonstration of real-time contingency plans at 23 AICRPDA Network centres. Real Time Contingency Planning (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" (Srinivasarao *et. al.*, 2016). The on-farm program is being implemented in 54 adopted villages in 26 districts covering 15 states. Since 2011, the AICRPDA-NICRA programme is being strengthened at network centres to address the emerging location specific weather aberrations such as delayed onset and in-season droughts in the domain of majority of the centres, excess rainfall events at specific locations and droughts and floods in north bank plain zone of Assam. The RTCP implementation was with two-pronged approach i.e., preparedness and real-time response. Identified suitable crops and varieties to cope with delayed onset of monsoon: For example, at Indore, for 14 delay in soybean cv. RVS 2001-4, JS 335, pigeonpea cv. C 11, ICPH-2671; at Biswanath Chariali for 18 days' delay, rice cv. Gitesh Ranjit; at Parbhani for 18 days' delay, pigeonpea cv. BDN 711; at Rajkot for 25 days' delay cv. groundnut cv. GG 20, sesame cv. G Sesame 2 and castor cv. GCH 7; at SK Nagar for 21 days' delay, pearlmillet cv. GHB 558, greengram cv. GM 4 etc. Developed 46 real-time contingency measures (soil, water and crop based) to cope with early, midseason and terminal drought in rainfed crops (Neog *et. al.*, 2016; Neog *et. al.*, 2020; Ravindra Chary *et. al.*, 2013; Ravindra Chary *et. al.*, 2020; Gethe *et. al.*, 2021).

Soil management

Integrated nutrient management (INM) studies have established the value of several 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 1030 kg N ha[1]. Short duration legumes such as cowpea benefitted much more. An integration of FYM (10 t/ha) + recommended NPK at Bangalore not only stabilized productivity and improved sustainability but also improved economics of production. 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 favourable 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 a new vista to make green manuring a viable option. Long term INM trials conducted for more than 20 seasons at AICRPDA centres 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 (Vittal *et. al*., 2005).

- **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, whereas inorganic C stocks increased with depth. Among the production systems, soybean-, maize-, and groundnut-based systems showed greater organic C stocks than other production systems (Srinivasarao *et. al.*, 2012)
- **Carbon sequestration strategies in 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 or organic manures. The mean annual C input were recorded maximum in soybean system followed that in rice and ground nut 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, 0.15% to 0.24% at SK Nagar, 0.35% to 0.53% at Indore and 0.24% to 0.34% at Varanasi due to different INM practices**.** The carbon footprints (Tg CE ha^{-1} $year^{-1}$) were higher in cereals cropping systems followed by oilseed and pulse systems. The carbon footprints per unit amount of yield (Tg CE Mg^{-1} grain) showed higher for rice (2.8800) - lentil (6.1463) sequence in Inceptisols (Srinivasarao *et. al.*, 2009)
- **Identified key soil quality indicators in diverse rainfed agroecologies***:* Organic carbon (OC), available N, P, K, S, exchangeable Ca, Mg and DTPA extractable Zn emerged as key chemical soil quality indicators in most of the rainfed soils. Among the set of biological and physical soil quality indicators, dehydrogenase activity, microbial biomass carbon and labile carbon, bulk density and mean weight diameter (soil structure) figured as predominant indicators. Based on soil quality indices, best soil and nutrient management treatments/practices were identified for rainfed production systems
- **Micronutrient research in rainfed production systems:** At Arjia, recommended dose of N&P with all limiting nutrients (Zn, B and Mg) gave highest maize grain yield (2474 kg/ha) ; at Bengaluru, rec. N and K + Lime @ 300 kg/ha + $MgCO_3$ @ 150 kg/ha + Borax @ 10 kg/ha recorded a higher fingermillet mean grain yield of 3580 Kg/ha ; in sorghum at Kovilpatti, maximum grain yield of 1624 kg/ha with 40 kg N/ha + 20 kg P/ha + 25 kg $ZnSO_4$/ha
- **Site specific nutrient management:** At Bengaluru, SSNM for a targeted fingermillet yield of 4.0 t/ha recorded higher mean grain yield (3760 kg/ha), followed by the application of recommended dose of . P_2O_5 + 125% Rec. N & K_2O + $ZnSO_4$ + lime application
- **Foliar spray of potassium for drought mitigation:** Multi-location experiments on diverse soil types and crops viz., Solapur, Maharashtra (*rabi* sorghum, Vertisol); Arjia, Rajasthan (maize, Inceptisols); Biswanath 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; RDF (40 kg N, 35 kg P and 15 kg K per ha) + 2% KNO3 before flowering in toria; 2% KNO3 at 60 DAS in groundnut and 2 % KNO3 in maize and chickpea has increased leaf water content during mid-season drought and were proven promising to overcome water stress conditions

- **Microbial consortia for drought tolerance in rainfed crops:** In semiarid Vertisols at Parbhani (in *rabi* sorghum) and in subhumid Inceptisols at Ballowal Saunkhri (in maize), seed treatment + soil application of microbial consortia (C1: *Pseudomonas putida* P7 + *Bacillus subtilis* B30 and C2: *Pseudomonas putida* P45 + *Bacillus amyloliquefaciens* B17) recorded significantly higher grain yield.

Energy management/Farm mechanization

- **Low till farming strategies identified:** Conventional tillage was superior at Bangalore for finger millet under semi-arid Alfisols; for pearlmillet under semi-arid Vertisols of Solapur and arid Inceptisols of Agra; for rice under moist subhumid Oxisols of Phulbani and dry sub-humid Inceptisols of Varanasi; for maize under dry sub-humid Inceptisols of Rakh Dhiansar; wheat under moist sub-humid Inceptisols of Ballowal Saunkhri; and for soybean under semiarid Vertisols of Indore. Low tillage + herbicide application was found to be superior for maize under dry sub- humid Inceptisols of Ballowal Saunkhri; soybean under moist subhumid Vertisols of Rewa; and cluster bean under semi-arid Aridisols of Dantiwada. Low tillage + hand weeding was found to be superior for pearlmillet under semi-arid Aridisols of Hisar; and groundnut under semi-arid Alfisols of Anantapur (Sharma *et. al.*, 2010; Maruthi Sankar *et. al.*, 2011).

- **Farm mechanization in rainfed cropping systems:** Mechanization of drylands reduced 20-59% operation cost, saved 45-64% in operation time, saved 31-38% seed & fertilizer and increased productivity of dryland crops by 18 to 53%. The energy requirement of major farm operations in dryland agriculture was worked out. Anantapur and Bengaluru centres developed energy efficient bullock/ tractor drawn implements/machinery for various agricultural operations. Complete farm mechanization package is developed for groundnut, *rabi* sorghum, maize and chickpea at various centres. The project over a period of time worked on suitable implements for mechanization of various agricultural operations. This 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%.

Alternate land use systems

In the Post 1987 era, the dryland agriculture research was much important due to shift from field crops to dry land horticulture plantation, particularly in shallow and slopy lands. The various alternate land use options were made available viz. agro-forestry systems (alley cropping, agri-horticulture, horti-pastoral system, agri-silvi-pasture system,), intercropping with nitrogen fixing tree species (NFTs) and ley farming in arable lands; and tree

AICRPDA Centre	Agroforestry system	Tree	Crop/grass
Arjia	Silvi-pasture	*Azadirachta indica* (Neem)	*Cenchrus ciliaris/ Stylosanthes hamata*
Akola	Agri-horticulture	Custard apple+ Hanumanphal	Green gram
Bengaluru	Agri-horticulture	Aonla	Finger millet
		Custard apple	Finger millet
Vijaypura	Agri-horticulture	Aonla+ Henna+ Custard Apple	Chickpea+ safflower
		Sapota + guava	Chickpea
Kovilpatti	Agri-horticulture	Sapota	Cotton
		Aonla	Greengram
		Custard apple	Greengram
Parbhani	Agri-horticulture	Drumstick	Blackgram
Rajkot	Agri-horticulture	Guava	Ground nut
Rakh Dhiansar	Agri-silviculture	Subabul	Wheat
	Agri-horti- silviculture	Guava+ *Melia dubia*	Setaria+ maize + gobi sarson
Solapur	Agri-horticulture	Aonla	Sunflower
Varanasi	Agri-horticulture	Guava	Pearlmillet
		Aonla	Greengram
Ananthapuramu	Agri-horticulture	Aonla	Fodder sorghum
Jagdalpur	Agri-horticulture	Mango	Fingermillet
Hisar	Silvi-pasture	*Azadirachta indica*	*Cenchrus setigerus*

farming/woodlots, range/pasture management, silvi-pastoral management system, timber and fibre (Timfib) system in culturable waste and marginal lands (Singh and Osman, 1995). 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 improvement, a noticeable improvement in crop establishment, survival and yielding ability occurred. Systematic designs were developed and improved to suit agroforestry. Management practices such as mulching, water harvesting, and soil amendments were evolved for marginal lands for improved survival of horticultural and forest tree species. Horti-pastoral system was identified as one of the potential alternative land use system options in shallow to medium deep soils to meet the growing demand of fruit and fodder, particularly to small ruminants. Studies 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 (Subudhi and Behera, 2008). Water supply to the plant can be improved by water harvesting using *in situ* or *ex situ* system. At Hyderabad, micro reliefs of 3 m width and 25 cm height, spaced 9 m from ridge, have been used to store extra rainwater for fruit trees such as kagzi lime, Coorg mandarin, and sweet orange with tomato and okra as intercrops (Singh and Vishnumurthy,1988).

A number of promising alternate land use systems were identified for different rainfall zones and soil types which included *agri-silviculture, agri-horticulture and silvi-pasture systems: Aonla* + greengram fodder in *kharif* and mustard in *rabi at* Rakh Dhiansar*; Aonla* + finger millet/ cowpea at Bangalore; Ley farming with *Stylosanthes hamata* with sorghum rotation), silivipasture with *Leucaena leucocephala* + *Stylosanthes hamata* + *Cenchrus ciliaris*, agro-horticulture with guava/custard apple/ pomegranate/ber based found better. The agroforestry systems developed at various Centres are given in table.

Integrated farming systems research

Research on integrated farming systems was started at AICRPDA centres in 1990s (AICRPDA, 2003). At Kovilpatti, an IFS model for 0.4 ha 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 (Soliappan *et. al.*, 2007). Other IFS modules suggested were, agroforestry+sheep based IFS at Anantapur, cereals, 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 research on agroforestry systems based IFS modules (with the components of perennials, annual crops, grasses, medicinal and aromatic plants, high value crops etc.) have been in progress at AICRPDA centres and now more priority is given for identifying/ developing farming situation specific IFS modules since 2006. Identified rainfed farming systems viz. at SK Nagar, integration of agricultural alone with livestock; at Bangalore, crops + dairy + sheep + goat + poultry + sericulture + piggery; at Kovilpatti (Tamil Nadu) showed that crop + goat (4) + poultry (20) + sheep (6) + dairy (1); at Bijapur crops, horticulture, goat and poultry and at Anantapur, sheep rearing (10 no.) and groundnut cultivation (1 ha) and groundnut cultivation (1 ha) + 1 jersey cow. Identified efficient integrated farming systems modules for scarce rainfall zone of Andhra Pradesh (Gopinath *et. al.*, 2013). 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 AICRPDA centres (Vittal *et. al.*, 2007).

Since 2018, Rainfed Integrated Farming Systems (RIFS) on-farm research has been redesigned as a flagship programme in AICRPDA. A standard methodology was developed for inventory and characterization of traditional rainfed farming systems in each AICRPDA centre's agro ecology. The predominant rainfed integrated farming systems (RIFSs) were characterized by surveying 5280 farmers (covering marginal, small and medium, and farming situations-rainfed and partially irrigated) by 22 centres (240 farmers each) in 132 villages of 44 blocks in 22 districts across 15 states. The traditional RIFSs were analysed and identified core RIFS practiced under rainfed conditions viz. crop + large ruminants, crop + small ruminants, crop poultry, crop + horticulture + large ruminants, crop + large ruminants + small ruminants + poultry and crop + poultry. Under partially irrigated conditions, the predominant RIFS are crop + large ruminants, crop + horticulture + large ruminants and crop + large ruminants + small ruminants + poultry. Stakeholder consultations were held in OFR-RIFS villages to prioritize component-wise interventions to strengthen traditional RIFSs. The interventions are being implemented under seven modules (as per the need) viz. NRM, crop, livestock, perennial tree, fodder, specific/optional module (interventions specific to individual farmers' needs) and capacity building.

Land use planning for management of agricultural resources in rainfed agroecosystem

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 Agroecosystem where in

400 interventions were demonstrated on 132 soil-sub groups on varying topo-sequences in 16 micro watersheds by 13 AICRPDA centres.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 (Ravindra Chary *et. al.,* 2008; Shankar *et. al.*, 2004) 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. Developed cadastral level soil-site specific cropping systems centred land use modules for higher land productivity in 19 micro watersheds across rainfed agro-ecosubregions. Developed a new concept and methodology of delineating each micro-watershed into homogeneous units viz., Soil Conservation Units (SCUs), Soil Quality Units (SQUs) and Land Management Units (LMUs) for soil and water conservation prioritized activities, for soil quality and carbon sequestration and for allocating land parcels to most suitable land uses (Ravindra Chary *et. al.*, 2015).

Technology assessment, refinement and development

One of the core objectives of AICRPDA is to evaluate and study transferability of improved dryland technologies to farmers' fields. In this regard, the coordinated efforts by AICRPDA centres are the best model for technology assessment and refinement and also technology upscaling in diverse rainfed agroecologies. Self-evaluation through ORPs is the hallmark of AICRPDA. On-farm participatory technology development has been a continuous process and delivered effectively through ORP in developing doable rainfed technologies (Sharma *et. al.*, 2010; Balakrishna Reddy *et. al.*, 2013; Ramachandrappa *et. al.*, 2014; Bhanavase *et. al.*, 2014; Kothari *et. al.*, 2016; Bhargavi *et. al.*, 2019). In the ORPs, the action research has been in the real farm situations. They demonstrated the economic viability, and feasibility of the recommended location specific technology. Feedback to research was an important conduit from the ORPs. Research findings from the main centres were assessed as action research through Operational Research Projects and feedback from farmers was given to main centres for refinement, if any. The revitalization of ORPs has been done by restructuring the ORP technical programme through Participatory Research Plans (PRPs) for Participatory Technology Development and Participatory Extension Plans (PEPs) for technology upscaling. PRPs and PEP s are now embedded in technical programme of ORPs for effective implementation, monitoring and evaluation for impact (Ravindra Chary *et. al.*, 2009). On-farm validation of contingency measures on real-time basis (delayed onset of monsoon, early/midseason/terminal drought/high intensity rainfall events). Soil moisture conservation practices on a small agricultural watershed including the development of water harvesting were also a result of the program. Another significant achievement was quantification of intercropping systems management and farm mechanization. Over a period, ORPs could give feedback on some of the technologies for refinement and many for wider adoption. Since NRM technologies are location-specific and needed continuous evaluation. The technology assessment and development at non-ORP centres has been through on-farm trials supported by AICRPDA and externally funded projects including state /SAU funded projects/ programmes.

Experiences gained (Post 1987)

Soil quality has been the major constraint in rainfed agroecosystems. During 2000 to till date, the research on Permanent manurial trials, INM, Tillage and nutrient management, could identify soil carbon management /carbon sequestration strategies to suit diverse rainfed agroecologies and also to enhance the crop productivity. Rainfed production system and soil-site specific soil quality indicators are identified which help in furthering the research focus on soil quality maintenance in soils of rainfed agriculture. The project since inception with a focused approach could identify/develop contingency measures to cope with drought. The recent high intensity rainfall events are recurrent during cropping season, particularly in Vertisol areas of Central India and Southern Deccan Plateau, enormously affecting production and productivity of rainfed crops. To address these issues, the research on contingency planning reoriented under NICRA to evaluate contingency measures on real-time basis at all centres to identify the risk resilient crop/ cropping systems, soil and nutrient management practices to cope with delayed onset of monsoon and in season drought. The impact of these studies indicated preparedness through rainwater harvesting and efficient utilization through life saving/supplemental irrigation, *in situ* conservation measures such as broad bed furrow, ridge and furrow system etc. enabled with energy efficient farm implements, short duration drought tolerant varieties and intercropping systems and implementation of contingency measures on real-time basis during delayed onset of monsoon and early/midseason/terminal droughts with various soil, crop and energy management strategies could enhance productivity and bring in resilience, to some extent, to the production system. However, timely availability of seed of contingency crop/variety and in desired quantity, availability of materials of foliar sprays, stored rainwater for life saving irrigation when needed, farm implements to take up sowings in large area within the limited moisture availability window are some of the major constraints in implementation of real-time contingency plans.

Sustaining the rainfed agriculture with stable productivity and profitability is the major concern. The research on alternative land use systems for stabilizing and maximizing productivity could be able to develop some agroforestry models matching specific agro-ecologies. Crop-livestock based farming systems have been the sustaining the rained farmers for their income and livelihood. With animal population dwindling and with forced non-farm income activities, the research focus is strengthening traditional arming systems with suitable components that enhance productivity, income and livelihoods and also act as adaptation/risk resilient strategy towards climate resilient rainfed agriculture.

Dryland technologies, which are primarily *"natural resource centered"* have to address the challenges of rainfall variability/ drought, land/soil quality deterioration, enhancing crop productivity for stabilizing production in diverse biophysical and socioeconomic settings of dryland agriculture. Over a period, it has been a daunting task for the project to generate dryland technologies as a package. Yet, the project succeeded in developing doable agroecology specific rainfed technologies that resulted in higher water/land productivity, enhance or maintain soil health, carbon sequestration, mechanization of dryland farming to some extent. However, as a System approach, the research in the project needs to be strengthened, may be with more human resources with needed expertise and knowledge, advanced research facilities and no doubt with high investment. Participatory technology development (PTD) is a continuous process in dryland agriculture research and development. With institutionalization of On-farm research at all the regular centres paved the way for technology assessment, refinement and upscaling under real-farm situation. Further, this mechanism also helped in on-farm participatory research on Integrated farming systems.

As far as technology upscaling is considered, the convergence mechanism needs to be strengthened since NRM technologies are "Capital intensive" which need multi-programme and multi-institutional strong collaboration ensuring the participation of primary stakeholders i.e., farmers, with much needed institutional and policy support from time to time for investments in dryland agriculture development.

Future thrust areas in dryland agriculture research

The major challenges for sustainable dryland agriculture are natural resource degradation, climate change, increasing food, feed and fodder demand and slow growth in farm income. These challenges demand a paradigm shift in formulating and implementing the dryland agricultural research programmes. Some perspectives as well as proposals for future dryland agriculture research are:

i) Addressing the challenges and opportunities facing the food and agriculture system: Focus of dryland agriculture research to be more on adaptation. . Innovation efforts should include focus on new crop varieties, crop protection, innovative rainwater management, responsible use of fertilizers, soil conservation, and adjustment in farming practices, etc. Increasing farm productivity on existing land should be a top policy priority as it is the most productive and environmentally friendly option available, and will address issues such as biodiversity, carbon sinks etc.

ii) Food security and environmental protection are not mutually exclusive goals: Integrated agriculture based on the judicious use of technology and inputs (such as seeds, manure, fertilizers and crop protection products) and good agricultural practices can increase farm production in a sustainable way. So there is an urgent need to develop appropriate technologies for precision farming.

iii) Agro-ecology specific resilient integrated farming systems: Dryland agriculture research has a key role to play in the innovative research needed to transform agricultural production systems in future. New food production models will have to be considered that will take account of ever decreasing resources while at the same time providing ever increased levels of output. Developing these new systems will result in a different approach to farming practices and the natural environment, the challenge being to develop integrated crop- tree-fodder-animal systems that increase agricultural output whilst simultaneously advancing environmental, economic and social goals. Focus should be on developing risk resilient and sustainable dryland farming systems.

iv) Sustainable intensification: The concept of *'sustainable intensification'* refers to the process of increasing agricultural yields without adverse environmental impact and without the cultivation of more land. This concept underlines the approach required by dryland agriculture research to the challenges outlined above. Dryland agriculture research must strive to develop new production technologies and approaches that maximize the benefits of natural resources while protecting and restoring these resources for future use. There must be a broad, inter-institutional and multidisciplinary approach to address these challenges in terms of crop diversification, enhanced food safety, improved natural resource management, biodiversity protection, climate change adaptation, energy security and meet the demand for environmental goods and services.

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