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Overview of Dryland Agriculture Research and Achievements in Southern Zone of Rajasthan

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Brief history of the Centre

The All India Coordinated Research Project for Dryland Agriculture Centre was established at Udaipur in 1976. The Centre was upgraded to the Main centre along with the Operational Research Project (ORP) and shifted to Agriculture Research Sub Station, Arjia, Bhilwara in 1984.

Agro-climatic zone characteristics

The Centre is located in Southern zone (NARP) in Rajasthan and in the Agroecological subregion (ICAR) 4.2 and in the Western plateau and hills agroclimatic region (Planning Commission). The climate in this zone is semi-arid. Out of the total annual average rainfall of 657.7mm, the south-west monsoon contributes 93.1% while 3.7% and 3.2% is from north-east monsoon and summer. The normal onset of monsoon is during first week of July and the normal withdrawal of monsoon is during first week of October. The historical rainfall data (of 30 years) indicated that the rainfall during south-west monsoon had been deficit by 17% of the average rainfall. The dry spells during crop season were experienced during September coinciding with reproductive stages of the major rainfed crops. Mean monthly rainfall is highest in August and lowest in February. Rainfall is relatively more erratic during rainy season (June – September). After every 3-5 years drought situations generally occurred and mid season and terminal drought situation occurrence is common phenomena in the zone, so that most crops affected adversely during *kharif* season. In the month of July and August mostly excess rainfall events occurs. Summers are hot and winters are cool. The maximum temperature is recorded in the month of May – June (upto 46.5^{0}C) and the minimum temperature in the month of January (upto -3.0 -4.0^{0}C) at Mount Abu.

Major soil types

The major soil types in the zone are loamy and clayey soils. Total geographical area of the agro-climatic zone IV-a of Rajasthan spread in 3354 thousand hectares. Out of this Inceptisols are 49.01%, Alfisols are 36.28%, Entisols are 5.30% and Vertisols & Elfisols are 9.36%.

Mean season-wise and annual rainfall and rainy days (1970-2021) at AICRPDA centre, Arjia, Bhilwara

Rainfall	Normal rainfall (mm)	Normal rainy days (No.)
South west monsoon (June-September)	626.0	30.6
Post monsoon (October–November)	15.4	0.4
Winter (December-February)	13.0	2.1
Pre-monsoon (Summer) (March-May)	23.4	1.2
Annual	677.9	34.3

Major rainfed crops cultivated in the domain districts

The major rainfed crops cultivated in the zone during *kharif* are maize, sorghum, blackgram, greengram, clusterbean, groundnut, cotton, sesame and soybean and during *rabi* are chickpea, mustard and taramira.

Dryland agriculture problems

Soil and land management

- Inadequate *in-situ* moisture conservation
- Excess runoff
- Poor soil fertility and imbalance use of fertilizers

Crop production

- Uneven distribution and erratic rainfall
- Prolonged dry spells and chronic drought
- Use of traditional varieties / mono cropping systems,
- Weed infestation and higher incidence of disease and pests
- Low adoption of improved crop production technology

Socioeconomic

- Fragmented land holdings, most of the farmers are small and marginal, low and erratic rainfall, four times drought in ten years,
- Improper rainwater management,

- Low level of mechanization,
- Decline in draught power and labour availability.
- Declining livestock population and non-availability of improved breeds of livestock
- Lack of access to credit facilities, input supply, marketing facilities

Research initiatives since inception of the centre

AICRPDA centre Arjia worked for generating the improved crop production technology for dryland agriculture in South East Rajasthan. Intensive research efforts have been made under the project to develop the technology for increasing and stabilizing the productivity of dryland agriculture in the region. Research activities primarily focussed in the identified thrust areas of resource characterization, cropping systems, rainwater management, integrated nutrient management, farm mechanization and alternate land use. Centres technologies enhanced production and increased income of farm families in rainfed areas. Centre involved in validation of adoptable dryland technologies with respect to changing climatic variables.

Significant achievements and findings

All India Coordinated Research Project for Dryland Agriculture (AICRPDA) centre at Agricultural Research Station, Udaipur, and Dryland Farming Research Station, Arjia have developed location-specific dryland technologies to cope with production constraints in the domain area. The key technologies are classified under resource characterization, catchment command relationship, rainwater harvesting, and recycling, *in-situ* moisture conservation, crops and cropping systems, participatory varietal selection of dryland crops, contingency crop plan to cope with delays in monsoon and during dry spells, integrated farming systems, energy management and alternate land use *etc*. The significant achievements of the center since its inception are briefly described under the following themes.

Resource characterization

The weather and soil data was analysed for resource characterization to characterize the earliest probable sowing time and defining the risk level in arable farming. Under dynamic and contingent crop planning for proactive monsoon management, sowing of crops may be started on 27th SMW, and the mean duration of the rainy season is 12.5 weeks (88 days) with a coefficient variation of 40.60 percent and recommended that short-duration crops of maize, sorghum, and pulses of 80-90 days maturity may be taken in Bhilwara and Udaipur districts.

During the study of 45 years of meteorological and soil data of Bhilwara (1960-2004), the district has hot dry summers with mean maximum temperature 39^0 C, mean minimum temperature 27^0 C, and cold winter with mean maximum temperature 23^0 C and mean minimum temperature 8 °C. The normal rainfall received is 669.1 mm, out of which 90% received during June-September. Total rainy days are 26 and mean pan evaporation ranges 14.4-72.5 mm/week. Onset of effective monsoon was found to be 27th week (2nd-8th July) and withdrawal of south west monsoon by 40th week (1st-7th Oct.), mid-season and terminal drought are likely to occur during the period of 33-35 weeks and 36th week onwards, respectively. Further, probability of occurrence of two consecutive dry weeks is high (61.90%) from 37th week onwards in this region.

Rainwater management

In-situ moisture conservation through flat sowing and ridging after first interculture improve different crops yield and widely adopted by the farmers of the zone. Soil and water losses reduced by adopting *in-situ* conservation practices like application of FYM @ 5 t/ha and vertical mulch of sesame straw @ 5 t/ha at 10 m interval reduced runoff, soil loss, increased water use efficiency, physical and biological properties like dehydrogenase and phosphotase activities of soil and also increased the yield of maize. Among various types of bunds tested, contour bund proved most effective in conserving soil and water and for increased yields of grass and tree growth. In Inceptisol soils of south Rajasthan, summer disc ploughing followed by cultivator recorded highest water use efficiency and produced lowest runoff and soil loss in the region. To overcome the adverse effect of sub-soil compaction in inceptisols and to break the hard pan in subsoil, ploughing with a Vibro chisel plough up to 40-70 cm depth at one and half meter interval once in two years was found useful and recorded 26.72% higher maize grain yield as compared to cultivator.

Also, research over the years revealed that the region experiences an average of 7-11 runoff events per year resulting in 2-2.5 tons of soil loss per hectare. The following are the significant findings over the years that found efficient for effective rainwater management. Dug-out ponds with the lining of calcareous soil recorded a minimum seepage rate (1.05-1.08 cm/sq m/day) and reduced the seepage by 62 percent as compared to the unlined ponds.

Farm pond of 1200 m^3 capacity (size 20 x 14.4 m with 3.0 m depth) with side slopes of 1:1 is sufficient for a catchment area of 2.5 ha. Soil + 500 µHDPE lining was found very effective in reducing seepage losses in zone IV-Arjia of Rajasthan. One supplemental irrigation of 5 cm to maize by sprinkler during dry spells at the grain filling stage enhanced the grain yield by 25-30%. Besides this, to minimize the evaporation losses from the farm pond, maize straw mat (6 kg m^{-2}) was found effective.

Crops and cropping systems

Crops and cropping systems help to cope with any adverse events like rainfall variability and drought. The cropping system-based strategies for drought mitigation in the domain area of AICRPDA- Arjia centre includes growing crops and varieties that fit into variable rainfall situation year to year. The maize varieties; Navjot, Pratap Makka (Composite)-3, Pratap Sankar Makka-3 PHM-3, PHM-5, PM-9, Pratap Maize Chari-6, DHM-117, DHM-121, HQPM-1, PQPHM-1, and blackgram varieties like PU-31, Pratap Urd-1, Mukndra-2, and KU-96-3 are suitable for rainfed conditions due to their tolerance to drought, early duration, and higher seed yield. Improved varieties recorded 12 to 18% higher yields than the local varieties.

Best yields of maize and sorghum were achieved when sown with blackgram and greengram as intercrops during the last week of June to 1st week of July. Intercropping of maize + blackgram (2:2) as paired row ratio instead of sole maize was found more beneficial and adapted by large number of farmers of the zone. If rainfall is delayed by a week (2nd fortnight of July), sowing of contingent crops such as blackgram, greengram, cluster bean, cowpea, and sorghum/ fodder sorghum are found profitable in the domain area. Among different rainfed crops, blackgram, cluster bean and sorghum can be grown as better alternate crops to maize in rainfed Inceptisols and *vertisol* as these crops gave maximum maize equivalent yield over years. Higher maize equivalent yield was recorded with strips of maize (grain) in 2/3 area + strips of maize chari fodder (1/3) area cropping system. Higher net returns were also recorded with maize + blackgram (6:6) row ratio at 45 cm, groundnut + pigeonpea (2:2), maize + soybean (2:2), castor + greengram (1:2) and groundnut + sesame (2:2) intercropping systems.

The fodder crops sown during delayed onset of monsoon, maize Chari fodder and fodder sorghum were found efficient in fodder production. Fodder sorghum and fodder maize are potential forage cereals because they can produce more quantity and quality fodder while also ensuring net monetary returns. Napier and Lucerne are also grown under partially irrigated areas of dryland regions for round the year in the domain area. Application of quizalofop-ethyl @ 50 g ha^{-1}at 30 days after sowing in blackgram significantly increased seed yield by 20.21 percent in comparison to weedy check.

Nutrient management

Under integrated nutrient management in maize, application of FYM @ 10 t ha^{-1} RDF (N90 P30 K30) and seed inoculation with *azotobacter* and PSB significantly increased yield attributes and yield (43.89%) over control. However, it has also improved the N, P, and K status of soil by 2.78, 4.31 and 8.56 kg ha^{-1}, respectively, and improved the nutrient content and uptake in grain and stover as compared to the control.

Management of zinc deficiency in rainfed maize, application of soil test based fertilizer (STBF) + zinc sulphate @ 25 kg ha^{-1}; STBF + P 33 microbial culture (seed treatment) and STBF + P29 microbial culture (seed treatment) at the time of sowing of rainfed maize increased yield significantly by 55.63% with application of $ZnSO_4$ @ 25 kg/ha but it was found at par with 33 microbial culture (42.55%) and P29 microbial culture (45.88%) over control. Application of K_2O @ 40 kg ha^{-1} increased maize yield (19.6%) over control (2066 kg ha^{-1}). Similarly, application of 30 kg $MgSO_4.7H_2O$ ha^{-1} increased the maize grain yield by 25.9% over control. It also increased the availability of K and Mg status in soil after harvest of maize crop.

Taramira crop was sown in conserved moisture, application of RDF (N20:P30:K0) with *azotobacter* + PSB seed treatment and spraying of vermiwash @ 7.5% at flower initiation and pod formation stage increased seed yield by 60% as compared to control (296 kg/ha).

Fifteen years of long-term integrated nutrient management experiment conducted at AICRPDA, Arjia revealed that, application of 25 kg N through FYM and 25 kg N through inorganic fertilizer + 30 kg P_2O_5 gave highest mean maize grain equivalent yield (3533 kg/ha) as compared to control (2057 kg/ha) with an increase of 71.72%. However, applications of organic treatments significantly affected the organic carbon, available nitrogen, phosphorus and potassium in both layers (0-15 and 15-30 cm depth) and recorded higher with the application of 25 kg N through FYM and 25 kg N through inorganic fertiliser + 30 kg P_2O_5.

In maize, foliar application of soluble complex fertilizer NPK (19:19:19) @ 0.5% + zinc sulphate @ 0.5% at both knee high and before tasseling stages increased the maize yield by 32 percent as compared to control. However, mitigate the dry spell stress effect in blackgram, by spraying NPKS (18:18:18:6) @ 2% before flowering and pod filling stage produced 31% higher blackgram seed yield over control (1074 kg /ha).

Energy management

Among different seed drills/planters tested for maize sowing, tractor-drawn nine row Arjia intercropping seed drill has sown maize + blackgram (2:2) intercropping system (paired row) with optimum seed rates of maize and blackgram. An interculture implement (tractor operated weeder) was fabricated with row distance adjustment for intercultivation in maize, blackgram and intercropping system. Tractor drawn interculture implements perform weeding and also ridging simultaneously. The strip cropping of maize + blackgram (4:8) with deep tillage and ridging after one interculture operation (RAFIO) was more energy efficient and increased the energy use efficiency by 33.35 percent in deep tillage as compared to shallow tillage. Arjia wheel hoe developed by the centre for all crops was fabricated

and tested in the field conditions is becoming popular among marginal and small farmers of the district. The field capacity of the Arjia wheel hoe has been found to be 6.55 man/day ha^{-1} as compared to kudali (23.9 man/days ha^{-1}). Dept. of agriculture, Dist Bhilwara included the equipment in its subsidy scheme for upscaling.

Alternate land use systems

The soils of the domain area are large, marginal and uncultivated waste land which are sandy loam, shallow in depth, undulating topography and poor in soil fertility. Class IV and V lands of zone IV-Arjia Rajasthan are hilly (4-15%) with these lands having only some trees and local grass species such as Aristida. These unproductive degraded pasture class V land can be made productive with silvi-pastoral system and recorded 239% more *Cenchrus setigerus* dry grass yield as compared to the control. Further, class V unproductive lands made productive by sowing *Cenchrus setigerus* as mud pellets/ balls with the application of 20 kg N and 30 kg P_2O_5 per hectare each year and recorded 103 percent higher dry grass yield as compared to local pasture. Also with agri-horti aonla based system and integrated with different need based crops and grasses like aonla+ sesame, aonla + pumpkin, aonla + aswagandha and aonla + *stylosanthes hamata* in class iv land as compared to fallow land. Further, unproductive class IV lands made productive with agri-horti system like ber + papaya + greengram, ber + papaya+ blackgram, guava + papaya + groundnut as compared to fallow land.

Integrated farming system

The research revealed that, for a farm of 1 ha of land, maize as a *kharif* rainfed crop with cow rearing (2) improved the total net returns by 92 percent compared to crop alone. Besides, it provides 67 man days of employment after harvest of maize to the farmer. Similarly, under partial irrigated conditions, agri-horti system groundnut + guava integrated with cow (2) + goat (2) rearing is an appropriate system in class IV land for semi arid region of Bhilwara for the best use of available natural resources.

Technologies developed

Rainwater management

- *In-situ* moisture conservation for higher productivity of maize
- Early *rabi* cropping of chickpea for green pods with harvested rainwater
- Rainwater harvesting through farm pond
- Artificial well recharge technology to increase ground water table
- Combat the dry spell effect in maize under real time contingent crop planning
- Planting technique for rainwater management in agro-horti system on cultivable waste land
- *In-situ* moisture conservation in ber based horti-pastoral system to enhance productivity of marginal land

Cropping system

- Developed improved horsegram variety Pratap Kulthi-AK-53
- Standardization of tassel removal from standing maize for alternative use under variable monsoon

Intercropping systems

- Maize + blackgram (2 :2)
- Maize + pigeonpea (1:1)
- Maize + castor (1:1)
- Sorghum + greengram (2:1)
- Pigeonpea + groundnut (1:1)
- Castor + greengram (1:2)
- Groundnut + sesame (6:2)
- Chickpea + mustard (Intra cropping) across the sowing of chickpea at 2.7 m interval

Double/triple cropping systems

- Maize-gram
- Sorghum-mustard
- Sorghum + cowpea (green fodder) -Tramira
- Blackgram-mustard
- Maize-chickpea + mustard (intra cropping)

Nutrient management

- Zinc nutrition in maize

Integrated nutrient management practices

Crop	INM Practice
Maize	15 kg N through FYM+10 kg N through subabul leaves before sowing and 30 kg P_2O_5/ha; 25 kg N/ ha at 30-45 DAS through urea 50% recommended through organic (FYM/compost) and remaining 50% through inorganic fertilizer and 30 kg P_2O_5/ha. **a. Seed treatment** Seed treatment with *Azotobacter* and PSB or microbial consortia along with recommended dose of fertilizers. **b. Foliar nutrition** Maize: Two sprays of 0.5% $ZnSO_4.7H_2O$ at 40-45 DAS and 60-65 DAS (1 kg $ZnSO_4.7H_2O$ + 0.5 kg lime mixed in 200 litres of water becomes a neutral solution of 0.5% zinc sulphate) or two sprays of soluble NPK (19:19:19) @ 2% at knee high stage and grain filling stage.

Crop	INM Practice
Sorghum	Application of 50% N through organic and 50% through inorganic (RD: 40N:20P) Seed treatment with *azosprillum* and PSB microbial consortia along with recommended dose of fertilizers spray of KNO_3 @ 0.5% at flag leaf stage.
Blackgram, greengram, clusterbean,	Seed inoculation with *rhizobium* and phosphate solubilising bacteria (PSB) microbial consortia along with recommended dose of fertilizers. One spray of soluble NPK (19:19:19) @ 2% at flower initiation.
Groundnut	Seed inoculation with *Rhizobium* and Phosphate solubilising bacteria (PSB) Microbial consortia along with recommended dose of fertilizers along with recommended dose of fertilizers. One spray of 0.5% $FeSO_4$ neutralized with 0.20% lime solution at flowering stage.
Soybean	Seed inoculation with *rhizobium* and phosphate solubilising bacteria (PSB) microbial consortia along with recommended dose of fertilizers. In soybean, spray 0.5% $FeSO_4$ and neutralized with 0.20% lime solution, if crop seems to be yellow.
Chickpea	Seed inoculation with *rhizobium* and phosphate solubilising bacteria (PSB) microbial consortia along with recommended dose of fertilizers.
Sesame	Seed inoculation with *azotobacter* and PSB culture or microbial consortia along with recommended dose of fertilizers
Mustard and Taramira	Two spray of vermiwash @ 7.5% at flower initiation and pod filling stage along with recommended dose of fertilizers.

Energy management

- Arjia wheel hoe for efficient weed control in rainfed crops
- Two row bullock drawn Arjia seed drill for rainfed crops
- Rota-till drill for ideal seedbed preparation and sowing of maize
- Rain water conservation through Vibro chisel plough and peripheral bunding
- Mechanization of intercropping system
- Mechanization of intercultural operations through tractor drown implements

Alternate land use

- Silvi-pastoral system
- Social fencing to develop community pastures in Southern Rajasthan

Contingency crop planning

a. Crops/cropping systems for normal onset of monsoon (15th June to 1st week of July)

- Maize (PEMH-2, Pratap hybrid maize-1, PratapMakka-3, Pratap Makka-5)
- Sorghum (Pratap sorghum-1430, CSV-17, CSV-15)
- Groundnut (TG-37A, Pratap moong phali-1&2)
- Blackgram (Pratap Urd 1, Mukndra-2, Mash 479, KU-96-3, PU-31)
- Sesame (RT-351, RT-346 and RT-127)
- Soybean (JS 93-05, JS 20-34, JS 71-05, JS 9560, Pratap Soya 2, Pratap Raj Soya 24)

b. Contingency crop /cropping systems and cultivars under delayed onset of monsoon

For *kharif* crop planning

a. Suggested contingency crops/cropping systems and cultivars under delayed onset of monsoon

Delay by 2 weeks (2nd week of July)

- Maize (PratapMakka-3, PM-9, Pratap hybrid maize-3; blackgram: PU-1, Mukndra-2)
- Intercropping system: maize+blackgram (2:2); groundnut (TG-37A, Pratap Moongphali-2); groundnut + sesame(6:2)
- Sole crops: soybean (MACS-58, PS-16, JS-335, JS-71-05, PratapSoya-1)
- Sorghum (Pratap sorghum-1430, CSV-17)
- Prefer sorghum + greengram (1:1) intercroppingat 30 cm spacing

Delay by 4 weeks (4th week of July)

- Maize fodder : African tall, Pratap Maize chari-6
- Sorghum (fodder): Raj chari-1and 2, Pratap chari-1080, SSG-59-3
- Greengram: K-851, IPM-02-03, SML-668
- Blackgram: T9, RBU-38); sesame (RT351,125and127
- Horsegram: AK-21, Pratap Kulthi-1 and Pratap Kulthi-2

Delay by 6 weeks (2nd week of August)

- Sorghum (fodder): Raj chari-1&2, Pratap chari-1080, SSG 59-3
- Pearl millet fodder: Narendra chara bajra -2, Gujrat fodder bajra-1
- Horsegram: Pratap Kulthi-1 and Pratap Kulthi-2

Delay by 8 weeks (4th week of August)

- Fallow-mustard (Bio-902, Laxmi)
- Fallow-gram (Dahod yellow, ICCV10, RSG-888, Pratap channa-1)
- Fallow-taramira (RTM2002, RTM-314)

b. Crop, soil, water and nutrient management strategies during seasonal drought

Early season drought

- Re sowing, if germination is less than 50% except groundnut and increase seed rate upto 20-25%.
- Gap filling, if germination is more than 75%, fill up the gaps through blackgram
- Gap filling, if germination is more than 75% and in groundnut, fill up the gaps through sesame and blackgram
- Soil mulch on upper top soil by hand hoe or other manual operated implement
- Spread available farm waste within rows of the crops as mulch
- Avoid top dressing
- In groundnut, gap filling can be done by sesame and in maize by blackgram or sesame
- Hoeing by hand hoe to develop soil mulch for conservation of soil moisture
- Weeding

Mid-season drought

- Reduce the plant population by thinning with in rows up to 30-50%
- Remove lower leaves of maize and sorghum and use as green fodder
- Foliar application of soluble NPK (19:19:19) @ 0.5% and zinc sulphate @0.5% during dry spell.
- Foliar spray of thiourea 0.1% in maize, sorghum and soybean and spray kaolin 5% as an anti-transpirant.
- Remove tassels of maize and use as fodder
- Earthing up done in maize, sorghum and groundnut at 30-35DAS.
- Soil mulching by light hoeing and prepare ridge and furrow in maize, sorghum and blackgram.
- Apply available farm waste between the rows for mulching purpose.

Terminal drought

- Harvest maize and sorghum for green fodder purpose
- Green cobs of maize marketed and maize plant used as green fodder
- Uproot groundnut and market as wet pods
- If crops damaged after long dry spells, prepare the fields for *rabi* crop
- Provide protective irrigation, if available
- Conserve the rainfall and sow *rabi* crops like chickpea, mustard / taramira etc.

***For rabi* crop planning**

Rabi crops may be sown on conserved moisture or harvested rainwater is available for application as pre-sowing irrigation for sowing the *rabi* crops/ supplemental irrigation. These are the following important crop and varieties for *rabi* season:

a. Crops and varieties for normal season

- Chickpea (CSJ 515, RSG 991, Raj Pratap Chana, Pratap Chana-1)
- Mustard (Bio 902, Laxmi, Pusa Sarson 25, Pusa Sarson 30)
- Lentil (IPL-81, DPL 62, JL 3)
- Linseed (Pratap Alsi-1, Chambal)

b. Suggested crops and varieties for sowing on conserved moisture or if rainfall is received in last week of September or first week of October and harvested rainwater is not available:

- Chickpea (Raj Pratap Chana, Pratap Chana-1)
- Taramira (RTAS, RTM 314, RTM 2002)
- Lentil (IPL-81, DPL 62, JL 3)
- Linseed (Pratap Alsi-1, Chambal)

Agri-horti /pasture/ silvi systems viz. crops, spacing, management practices

- Ber + *Cenchrus* spp. (5 m row to row and 5m plant to plant)
- Khezri/neem + *Cenchrus* spp. (boundary plantation of tree)

Variety of fruit crops and field crops

- Ber - Umran, Gola, Apple
- Aonla - Hatijhul, Banarsi, Chakya, NA-7, Krishna
- Guava - L-49, Pant Parbhat, Saweta, Lalit
- Custard apple - NMK-1, Anona-2, Arka Sehn, Balanager
- Sapota - Kali Patti, Cricket Ball, DH-1, DH-2
- Lasora - Thar bold, Karan Lasora-1
- Chickpea - Partap Chana -1, GNG-1958, GNG-2144, CSJ-515
- Linseed - Chambal, Jawahar-17, Jawahar-7 (R-7), M-10, LC 185, Hira, Mukta, Neelum, B-67,
- Taramira - RTM-314, RTN-2002, RTM-1351
- Lentil - PL-9, PL-406
- Cencurs - CAZRI-76

Technologies upscaled in convergence with various programmes

AICRPDA centre Arjia has developed many location-specific dry land technologies for the benefit of farmers. Successful technologies were upscaled in convergence with Govt. programmes, NGOs, and KVKs after demonstrating in the farmer's field. In convergence, the collaborated institutes encouraged the farmers to adopt these technologies to cope

with the climate vagaries and also enhance the productivity of rainfed crops in the zone. The technologies developed by the centre were adopted by the Department of Agriculture, Govt. of Rajasthan, KVKs, NGOs and also included in the Zone IV-arjia package of practices (PoP) of MPUAT Udaipur.

Impact of technologies

The dryland technologies developed by AICRPDA - Arjia have significantly improved the productivity of rainfed crops grown in dryland areas of Rajasthan. Farm pond technology is one such technology that is more popular, climate resilient and successful in rainwater harvesting and mitigating the zone's frequent dry spells. The impact of technologies was clearly visible with increased productivity, yield stability and improved livelihoods for farmers in the region. The impact of the technologies in terms of yield enhancement and overall productivity improvement in the zone are shown below.

Rainwater management

- *In-situ* moisture conservation model for maize/ sorghum and maize + blackgram (2:2) crop and cropping system practices increased the maize equivalent yield by 21-25% as compared to farmer's practice.
- Utilization of harvested rainwater in maize + blackgram (2:2) and groundnut + sesame (6:2) intercropping system. Supplemental irrigation increased the maize and groundnut equivalent yield by 15-28%

Crops and cropping systems

- Intercropping system maize + blackgram (2:2) and groundnut + sesame (6:2). Both intercropping systems practiced by the farmers in medium to deep soil increased the grain yield by 25-47% in domain area. They get approximately an additional income @ Rs. 4966 - 8435 per $ha^{-1.}$
- Intercropping system sorghum + greengram (2:1) and blackgram + sesame (2:2). These intercropping systems were practiced by the farmers in shallow to medium-depth soil and increased the grain yield by 21-34% in the domain area. They get an approximately additional income of Rs. 2587-3945 ha^{-1}
- Contingency crop planning reduced the weather risk and brought stability under delayed monsoon situation as contingent measure sorghum (fodder) and greengram was sown. If monsoon is very delayed, then in place of the *kharif* crop, taramira can be sown during September.
- Sorghum, cluster bean, greengram and cowpea, can be grown as alternate crops to maize and these crops were grown successfully by the farmers in Bhilwara region.

Impact of dryland technologies developed at AICRPDA-Arjia centre

Nutrient management

- Enhancing productivity of rainfed maize through use of agro-chemicals (Foliar spray of KNO_3, soluble NPK, and thiourea). Foliar spray of 1% KNO_3, soluble 1% NPK, and 500 ppm thiourea application in maize increased the maize yield by 18-35 %
- Seed priming of sorghum with thiourea (0.1%) and maize with KH_2PO_4 for crop establishment and contingent planning. Seed priming of sorghum with thiourea @ 0.1% and maize with KH_2PO_4 @ 2% increased the crop yield by 12-23%.
- Combating the dry spell effect through foliar application of NPK (19:19:19) @ 0.5 % + $ZnSO_4$ @ 0.5% in maize crop during the dry spell was popularized and adopted by 25% in the domain area.
- Application of PROM (Phosphate Rich Organic Manure) @ 30 kg per ha in maize + blackgram (2:2) intercropping system recorded 16% higher maize grain equivalent yield in comparison to DAP fertilizer.
- A large number of farmers of the zone prepared compost by the NADEP method and get nutrient-rich organic manure as compared to the open heap manure system.
- Application of 125% recommended N in sorghum improved the grain yield by 22% with additional net return of Rs. 5957 ha^{-1} in comparison to the recommended practice in the domain area.
- Application of gypsum @ 120 kg ha^{-1} in groundnut enhanced the pod yield by 15% with an additional net return of Rs. 11674 ha^{-1} being followed by the dryland farmers in Bhilwara region.

Energy management

- In Bhilwara district, large number of small and marginal farmers use Arjia wheel hoe and 2 HP power weeder for interculture in different crops and saved 30-35% cost and 68-83% time ha^{-1}
- Tractor drawn multi-crop planter and interculture implement (tirri) with slight modification (in rim and tyre of tractor) is successfully used by the farmers and saves 80% time and 41% cost per hectare.
- Tractor drawn intercropping seed drill developed by the center which made sowing of maize + blackgram (2:2) paired row system saved 28-35% cost and 65-78% time.

Alternate land use /agroforestry systems

- Developed the silvi-pasture on farmers' field (Desi babool/ khejri + *Cenchrus setigerus*) and improved the grass production @ 54-120 t in sustained manner and obtained additional net returns of Rs. 4540 - 7090 ha^{-1}

- Aonla based agri-horti system and ber + *Cenchrus* grass (horti-pastoral system) adopted by large number of farmers on wasteland and increased productivity in a sustainable manner in the domain area.

Way forward

In view of the current changes in climatic conditions, farmers' awareness, cropping pattern and for increased productivity, the centre may have to reorient its work focusing on the following points.

- Strengthening the data base on climate, soil and plant resources to develop strategies to mitigating the effect of climate change using the GIS and remote sensing technology.
- Strengthening the technology for drought preparedness and amelioration measures during drought situation.
- Development of technologies for crops and cropping systems for sustained production
- Introduction and economic evaluation of non traditional crops like medicinal, aromatic and dye yielding species to augment the income per unit area.
- Development of a rainwater management model consisting of *in-situ* rainwater management practices, harvesting runoff, lifting mechanism of harvested water and efficient cropping systems.
- Integrated nutrient management with emphasis on *in-situ* generation of biomass and incorporation into soil through agro-waste management to maintain the soil health.
- Evaluation of new cultivars under varying rainwater management practices and compatibility analysis for different cropping systems.
- Evaluation and development of need based farm mechanization to improve the timeliness and precision in farm operations in face of acute shortage of agricultural labourers.
- Ergonomics of farm women at home, farm and allied activities to reduce their drudgery.
- Development of Climate Resilient Farming System models capable of harvesting the potential yields during normal season as well as aberrant weather situations.
- Evaluation of organic farming including residue management, bio-fertilizers and role of legume in rotation.