

Six-decades journey of CAZRI

addressing arid zone crop production system in inclusive way

O.P. Yadav¹

Central Arid Zone Research Institute, Jodhpur (Rajasthan) 342 003

The Indian arid regions, covering about 12% geographical area of the country, are perpetually under stress due to climatic factors and high human and livestock density. Existing levels of desertification and land degradation make farming a challenging task. The Central Arid Zone Research Institute, established in 1959, is exclusively mandated to address all issues related to farming in these regions. During the last six decades, the Institute has carried out systematic research on understanding the process of desertification; managing natural resources; developing sustainable farming systems; improving crops, grasses, shrubs, trees and horticultural crops; managing livestock and rangelands; and harnessing solar energy for the use in agriculture and society. Consequently, several need-based and cost-effective technologies were developed and transferred to farmers and stake-holders to enhance livelihood security in arid production environments and to contain desertification. Commemorating the Diamond Jubilee year of CAZRI, a brief overview of strategic research conducted in the Institute during last six decades, documents its major achievements and highlights the impact are discussed here.

Key words: Arid regions, Biodiversity, Farming System, Livestock, Rangelands, Solar Energy

THE Indian arid zone is spread over 39 million ha out of which 31.7 million ha covering about 10% geographical area of the country is classified as hot arid zone and another 7 million ha covering about 4% geographical area as cold arid zone (Fig. 1). Arid zone characteristically have low precipitation in comparison to high potential evapo-transpiration.

Resource limitations like low and erratic rainfall (100 to 450 mm annual rainfall with >50% CV), temperature extremes (45° to 50°C during summer whereas 0° to 4°C during winter in hot arid regions; 35°C to -35°C in cold arid regions), high wind speed (10 to 20 km h⁻¹) especially during summer, high annual potential evapo-transpiration (1,500 to 2,000 mm), sandy soils with low water retention capacity and poor fertility, scarce surface water resources, poor quality groundwater and declining groundwater-table

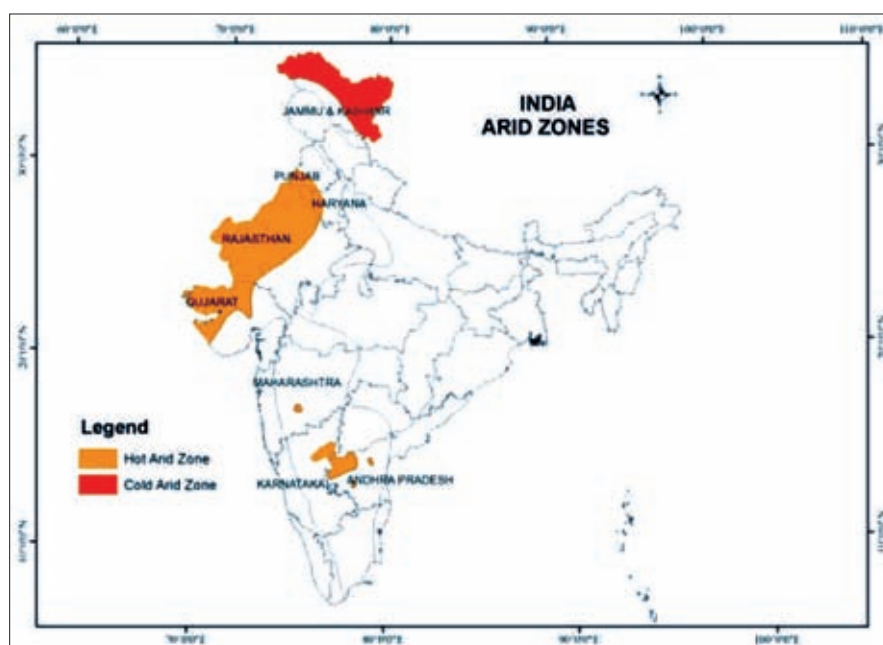


Fig. 1. Spread of arid zone in India

make farming a challenging task. These fragile agro-ecosystems are perpetually under stress due to increasing human and livestock

population and are continually prone to desertification and land degradation. As a result, the productivity of system is low and

chances of failure of annual crops are very high.

The Central Arid Zone Research Institute, a constituent of the Indian Council of Agricultural Research, is exclusively mandated to address all issues related to and affecting farming in arid regions. Commemorating the Diamond Jubilee year of Central Arid Zone Research Institute (CAZRI), an attempt is made here to briefly present an overview of strategic research of the institute, is undertaking to document its major achievements and to highlight the impact.

Historical background of CAZRI

Alarmed by the apprehension in early fifties that the Thar desert in Rajasthan might advance to Delhi and other parts of country, the Government of India established a 'Desert Afforestation Research Station' at Jodhpur in 1952 primarily for stabilization of sand dunes and establishment of shelterbelts to reduce wind erosion to contain the spread of the desert. The research station was reorganized in 1957 as 'Desert Afforestation and Soil Conservation Station'. On the recommendations of Dr C.S. Christian, a UNESCO expert from CSIRO, Australia, and Government of India reorganized the research station into a major centre for undertaking arid zone research, namely Central Arid Zone Research Institute in 1959. While proposing the institute, the guiding principle was to harness the strength of region in mixed agriculture consisting of crops and livestock recognizing fragility of arid landscape. The CAZRI was one of the primary institutes at international level funded by UNESCO under its programme of International Studies of Arid Zone. On April 1, 1966, CAZRI was brought under the administrative control of the Indian Council of Agricultural Research.

Since its inception, the Institute is working on understanding the issues related to production systems of hot arid zone of India and finding their sustainable solutions. Recently, work on cold arid zone is initiated with the establishment of Regional Research

Station at Leh.

During past six decades, arid regions have witnessed considerable change due to technological interventions in farming. There are also changes in natural resource base, demographic factors, infrastructure development etc.

During first two decades of its establishment, greater emphasis was given to assessment of land, soil, water and vegetation resources of arid and semi-arid regions; to obtain an understanding of the amount and fate of water received through rainfall, and surface and sub-surface flow; and to identify natural plant communities (trees, shrubs and ground flora) in adaptation and usefulness. In next two decades, major emphasis was on developing efficient methods of production involving different land use systems; to understand soil-land-water and plant-animal continuum with a view to optimum utilization of each component; and to understand socio-economic impact of drought, desertification, migration and pastoralism. In the last two decades, institute is engaged in undertaking basic and applied research for developing sustainable farming systems and range management practices for the chronically drought-affected areas; and continuously monitoring the state of natural resources and desertification. The five Regional Research Stations of Institute located at Bikaner, Jaisalmer and Pali in Rajasthan; at Kukma-Bhuj in Gujarat and at Leh in Jammu and Kashmir are doing innovative work on the region-specific issues in generation and transfer of location-specific technologies.

Broad areas of research for development

The Institute follows multi-disciplinary approach to address the problems of arid agriculture in inclusive way. During the last six decades of its functioning, the Institute carried out systematic research on understanding the process of desertification; managing the regions' natural resources including land, water, soils, vegetation, livestock; developing

suitable and sustainable cropping/farming systems; improving field crops, grasses, shrubs, trees and horticultural crops; managing livestock and rangelands; and harnessing solar energy for use in agriculture and society. Several need-based and cost-effective technologies like sand-dune stabilization, wind erosion control, water management, new stress-adapted field and horticultural crops and cultivars, watershed development, rehabilitation of wastelands, alternate land use strategies, new fodder crops, value-added products, pest management, solar devices etc. were developed and transferred to farmers and stakeholders to enhance livelihood security in arid production environments.

The Institute has developed close liaison with several national and international organizations and has made major stride in providing advisories and consultancies to many agencies in India and abroad. Also, CAZRI is a major destination for capacity building activities on arid zone development for scientists, policy planners and extension personnel. Through its outreach programmes, the Institute remains in direct touch with farmers, state government officials, NGOs and other stake-holders.

Assessment of natural resources

The state of natural resources is always a key factor in determining farming practices. Also, if the farming is not undertaken with due cognizance of natural resources, there might be short-term gains but in long-term, land degradation might be the end-result. Therefore, the Institute has conducted integrated surveys for assessment of natural resources of the Indian arid zone on about 26 million ha area in Rajasthan, Gujarat, Punjab, Haryana and Karnataka. Remote sensing and ground verification techniques are used to gather data on landform, land degradation status, soil type, composition of vegetation, surface and groundwater and land use. Data is integrated into a conceptual framework of Major Land Resources Units for devising sustainable



Fig. 2. A view of active sand dune (left), chess-board pattern of micro-wind breaks (middle) and stabilized sand dune (right)

development plans taking into consideration the socio-economic conditions of farmers from surveyed areas.

Land forms: The arid zone has very diverse types of land forms that are amenable to various degree of degradation. The Institute contributed for the National Working Group on Desertification Mapping and Monitoring as well as on desertification control. Nine major dune types, belonging to old dune system and new dune system, cover about 48% area of western Rajasthan. Wind erosion is identified as a major hazard and computation of wind erosion index for different parts showed that the severity of potential erosion varies from very low (index: 1 to 14) in the eastern parts of the arid zone to extremely high (480 and above) in the western parts. The mapping and interpretation of AWiFs satellite images for 2003 to 2005 periods at 1:1 M scale showed that out of 17.64 million ha (83.85%) area of western Rajasthan affected by various degradation processes, about 76% was affected by wind erosion. Mapping between 2011 and 2013 showed decrease in total degraded area by 8,41,596 ha (~3.85%) and area affected by wind erosion by 8,10,036 ha (~4%) compared to 2003 to 2005 data.

Soils: Institute has made tremendous efforts in assessing type of soils existing in different areas of arid zone and in understanding physical and chemical properties of these soils. The soils of hot arid region belong to Entisols, Aridisols and Alfisols soil orders. The Entisols are most predominant covering 17 million ha (54.2%), followed by Aridisols (45.1%) and Alfisols

(0.7%). Entisols are generally found in those parts of arid regions where high aeolian or fluvial activities are observed. Aridisols are dominant in parts where aeolian activity is comparatively less. The soils are mostly coarse textured having low silt and clay contents, low in organic carbon (C), but high in CaCO_3 , gypsum and salt contents with an impervious calcic or gypsiferous hard pan. Nitrogen (N) is low in most of the soils (94% area), while phosphorus (P) is low in 42% area and potassium (K) is low in 12% area. Zinc (Zn) and iron (Fe) are below critical limit in 68% and 60% area, respectively.

Vegetation: The western arid zone is hotspot for rich biodiversity. The flora of arid regions consisting of grasses, shrubs and trees are widespread in grasslands and woodlands. A large proportion of native vegetation is extremely useful and possesses exceptional ability of regeneration and has played a very important role in soil conservation. The most common multipurpose tree is *Prosopis cineraria*, a deep rooting leguminous tree which withstands lopping to a remarkable degree. The most dominant shrub is *Ziziphus nummularia* used for fodder and thorn fences. Prominent shrubs on sand dunes are *Calligonum polygonoides* and *Leptadeniaa sartium*. Very valuable and palatable perennial grasses include *Sewan (Lasiurus indicus)* performing well under extremely low rainfall conditions followed by *anjan (Cenchrus ciliaris)* and *dhaman (C. setigerus)*.

The spread, composition and richness of species was considered as one of the indicators of degradation. Increased grazing pressure in

rangelands was found to result in disappearance of some species and decline in biomass yield and seed bank of others species. The species richness increased due to moderate grazing pressure, but declined gradually with further increase in grazing pressure. Under extremely high pressure of grazing, the proportion of palatable species decreased and that of non-palatable species increased. Satellite-derived PD-54 index was found to be a good measure for locating degraded vegetation cover.

Land use: The land use has witnessed very significant changes during last six decades. Marginal and fallow land has been brought under plough to meet the demand of increasing human and livestock population. For instance, out of about 20.8 million ha geographical area of arid Rajasthan, net sown area was 40% of total area in 1960-61 which was increased to 56%. Similarly, area under culturable wasteland came down from 23% to 16%. The net irrigated area and double cropped area in hot arid regions of India was increased by 128% and 70%, respectively from 1982-83 to 2005-06. The changes in physico-chemical properties of soil under different land use were quantified.

Water: The water is the most important resource for agriculture and allied activities, the Institute initiated search for buried streams in the desert as early as in 1960s. Studies revealed some hitherto unknown early courses of the Saraswati and the Drishadvati rivers of the Himalayan origin and several streams of the Luni drainage system from the Aravalli ranges, which are

now buried under sand dunes and sand sheets. The drying of the Saraswati river system was linked to shifting of the Sutlej course, tectonic disturbances and climate change. These findings helped in locating potable groundwater at shallow depth and explained water-logging and salinization in the region.

About 15% area of north-west arid zone receives water through canal network. The *Indira Gandhi Nahar Pariyojna* (IGNP) covers about 0.55 million ha command area under Stage I, and 1.41 million ha under Stage II. It has led to introduction of crops like rice, groundnut, castor, chillies etc. that were considered alien for arid environments. Groundwater is over exploited for irrigation wherever its quality is good, except in some areas of Ganganagar and Hanumangarh districts where canal water is the major source of irrigation. Out of 90 blocks of arid areas in Rajasthan, groundwater is over exploited in 60 blocks, whereas 4 blocks are in critical and 3 in semi-critical category.

Climate change: It is a reality now expressed in form of increased temperature; varying timing, pattern and intensity of rainfall; increased incidence of extreme rainfall events; and shifting of crop seasons. The temperatures in arid zone are also increasing due to climate change but there are no indication of major change in rainfall amount. High thermal regime is likely to exacerbate the drought impact under rainfed conditions as increased temperature leads to higher evapotranspiration in crops. *Rabi* crops were started facing the adverse impact of temperature rise resulting in delayed sowing and high temperature stress at the maturity.

Management of resources

Management of natural resources was a top priority of Institute. Following intensive research in understanding the desertification process, CAZRI has developed several resource management technologies such as sand dune stabilization, shelterbelt plantation, soil and water conservation, management of saline-sodic soils, rehabilitation of mine spoils etc to

combat desertification and land degradation that has led to provisioning of enhanced cultivation and ecosystem services, which need to be quantified in economic terms using suitable indicators and parameters.

Sand dune stabilization: Sand dunes cover major part of arid region and therefore, work on sand dunes stabilization was given high priority in 1960s. The technique consisted of fencing of the area, establishment of micro-wind breaks on the windward side of the dune in 5 m chessboard pattern or in parallel strips, and sowing of grasses and transplanting of trees and shrubs with the onset of rains. For micro-wind breaks, locally available brushwood materials like *Colligonum polygonoides*, *Crotalaria burhia*, *Leptadeni apyrotechnica*, *Ziziphus nummularia* and *Panicum turgidum* were used. *Lasiurus indicus* and *Cenchrus ciliaris* were identified as suitable grasses, while suitable tree species included *Acacia tortilis*, *Prosopis* spp., *Acacia jacquemontii*, *A. nubica*, *Colophospermum mopane* and *Tecomella undulata*. Based on this technique State Forest Department is reported to have fixed sand dunes in about 0.4 million ha area (Fig. 2).

Wind erosion control in crop lands: Strip cropping of grass with crop (6:1 ratio of crop: grass strip); leaving about 6" (15 cm) stubbles of pearl millet in the field at the harvesting; micro-wind breaks of castor and grasses; creation of a cloddy surface; ridge-furrow cultivation and shelterbelt plantation were found very effective in reducing wind erosion from agricultural fields.

Shelterbelt plantation: Depending on degree of wind erosion hazard, three- or five-row shelterbelts in pyramidal shape were developed. *Ziziphus mauritiana*, *Acacia bivenosa*, *A. amplicep*, and *Calligonum polygonoides* were found to be suitable shrub species for flank rows; and *Acacia nilotica*, *A. tortilis*, *Azadirachta indica*, *Cassia siamea* and *Albizia lebbek* for central rows. The Institute erected and maintained shelterbelts of about 500 km length on roadside, rail-track side and canal side plantation that were subsequently handed over to the respective

departments. This has significantly reduced sand deposition in canals, on roads and railway tracks leading to improved water flow in canals and uninterrupted movement of vehicles and trains.

Rehabilitation of rocky and mine spoils areas: Rocky landscape is prevalent in several parts of arid zone. Out of several tested species, *Acacia tortilis*, *Prosopis juliflora*, *Acacia senegal*, *Grewia tenax*, *Anogeisus rotundifolia* and *Euphorbia caducifolia* were identified as suitable tree species for rocky and shallow gravelly habitats. Reseeding with *Cymbopogon jwarancusa* and *Cenchrus setigerus* also provided good results in shallow lands (<10 cm soil depth), while *Dichanthium annulatum* and *Cenchrus ciliaris* proved better in land having 10 to 20 cm soil depth.

Mining for gypsum, limestone, marble, sandstone, calcite, feldspar, zinc etc. were resulted in land degradation near such sites. Use of suitable amendments (pond silt, sewage sludge, farmyard manure and normal soil) along with arbuscular mycorrhizal fungi/*Bradyrhizobium* followed by planting of species like *Acacia senegal*, *Prosopis juliflora*, *Tamarix aphylla* and *Cercidium floridum* in micro-catchments, made for water harvesting, was found to be highly effective for rehabilitation of gypsum and limestone mine spoils.

Management of lands irrigated with poor quality water: Irrigation with high residual sodium carbonate (Na_2CO_3) waters results in sodification of land. Application of gypsum at 50% of gypsum requirement of soil plus additional quantity sufficient enough to neutralise the Na_2CO_3 in excess of 10 me/litre⁻¹ provided good results resulting in good crop yields.

Water conservation: Given very limited rains in arid zone, every drop of water needs to be conserved and used for farming. Small interventions like field bunding, contour bunding, mulching (soil mulch, crop or grass residue) and use of pond silt were found effective for conservation of water leading to availability of higher moisture in soil profile. Vegetative barriers of *Cymbopogon jwarancusa*, *Cenchrus ciliaris* and *C. setigerus*

across the slope of cultivated fields proved effective in conserving moisture and increasing crop productivity.

Watershed management: The watersheds are of paramount importance for soil and water conservation, recharge of groundwater, increasing vegetation cover and obtaining additional production in the area. The Institute developed more than 6,000 ha area under Jhanwar, Sar, Baorali-Bambore, Kalyanpur and Kukma watersheds. A watershed, covering an area of 1,200 ha was developed at Jhanwar village. The rocky and gullied catchments were treated with mechanical and vegetative measures, which resulted in 8-fold increase in biodiversity and rise in groundwater-table in the watershed. Overall resource conservation and availability of irrigation water promoted adoption of agri-horticulture system and improved dry farming technologies resulting in increased crop productivity by 25 to 30%. About 60 ha of community land was developed as an ideal pasture. This watershed was recognized by the United Nations Environment Programme for outstanding contribution in combating desertification and controlling land degradation. Where there is no clear drainage system and internal drainage is choked in sand dune complex, the 'Index Catchment Approach' was used, where the catchment is demarcated by considering the crest line of sand dunes or eroded rocky outcrops from the line of water divide.

Water harvesting: Traditional water harvesting systems, devised by local populace, were studied and improved to enhance their utility and efficiency. Improved designs of *tanka* (cistern; 10,000 to 6,00,000 litre capacity) were prepared providing access to safe drinking water to both for human and livestock in villages. Losses due to leaching in *talab* (pond) were minimized with low-density polyethylene sheet lining, silt trap etc. that provided water for a longer time. Similarly, water and soil conservation techniques and improved agricultural practices were developed and standardized for



Fig. 3. Integrated farming system having crops, grasses, horticultural crops and trees

khadin (water harvesting structure).

Inter-row, inter-plot and micro-catchment techniques were also standardized for rainwater harvesting. Micro-catchments produced 13 to 32% of rainfall as runoff at 0.5% slope and even higher amounts at 5% (36 to 45%) and 10% (26 to 44%) slopes. Inter-row water harvesting through ridge and furrow (50-60 cm wide ridge with 30-40 cm furrow) planting system was also established as useful.

Circular catchments of 1 to 2 m dia were effective for raising fruit plants and trees in levelled fields, while half-moon terraces were more effective on sloping lands. A double-wall earthen pot, named *Jal tripti*, was developed for raising tree saplings, which could save water up to 80 to 90%.

Rainfall-runoff studies in small catchments showed that polyethylene sheet generated maximum runoff (93%). Roofs of corrugated GI sheets generated 86% runoff, followed by stone slab roofs (81%), paved surfaces (69%), clay tile roofs (57%) and thatched roofs (32%). Threshold rainfall to generate runoff from different catchments were worked out which ranged from 3.1 mm for plastic surface to 9.5 mm for thatched straw roof.

Suitable cropping and farming systems

Given low and highly erratic rainfall in arid regions, cultivation of a single crop or commodity always run the high risk of failure. To minimize such prevalent risk, appropriate combinations of field crops, grasses, shrubs, trees,

horticultural crops, and livestock impart greater stability to production system as compared to crops alone and simultaneously fulfill the requirement of food, fodder, fruits and fuel wood. Several combinations of crops, agroforestry, and agri-horti-silvi-pasture-livestock were evaluated to enhance land productivity, better resource utilization, augmenting income and to provide employment throughout year. Appropriate combinations of different components were worked out for various rainfall scenarios. For example, silvi-pasture systems comprising of *Ziziphus rotundifolia* + *C. ciliaris* or *Lasiurus indicus* for raising cattle or sheep and goat are more suitable for <300 mm rainfall zone. Agri-horticulture systems involving *Ziziphus rotundifolia* + moong bean, moth bean or cluster bean and *Z. mauritiana* + moong bean or cluster bean, respectively, were found suitable for >300 mm rainfall zone. Similarly, intercropping or strip cropping of pearl millet and arid legumes were found to utilize resources more efficiently. Substantial improvement in soil biological activities was also observed under agri-silvi system compared to sole crops.

The Institute has developed a 7 ha integrated farming system model under rainfed conditions consisting of arable crops like pearl millet, moong bean, moth bean; grasses, *Prosopis cineraria*, *Hardwickia binata*, *Ziziphus mauritiana*, *Colophospermum mopane* and *Acacia tortilis* to maintain seven adult cattle units of livestock; providing gross returns of ₹ 4.59 to



Fig. 4. Sprinklers being used in wheat at CAZRI in 1972

5.16 lakh/annum with a B:C ratio of 1.76 to 1.96 and generating employment of 823 to 931 man-days annually (Fig. 3).

Conventionally, farmers cultivate pearl millet, cluster bean, moth bean, moong bean and sesame as mixed crops in different combinations. Mixed-or inter-cropping was found to improve soil fertility and make better use of resources than sole cropping, besides providing insurance against complete crop failure. In <350 mm rainfall zone, intercropping of pearl millet with legumes in replacement series (proportional reduction in component population) was found better whereas in higher rainfall zone and in fine-textured soils, additive series was better. Intercropping of pearl millet with legumes like clusterbean or moong bean or moth bean in different row arrangements mostly gave higher pearl millet equivalent yields and better land equivalent ratio. Intercropping of grasses like *Cenchrus ciliaris* and *Lasiurus sindicus* with legumes moth bean, clusterbean or moong bean) increased the fodder yield of grasses between 20 and 30% as compared to grasses alone on deep loamy soil. Long-term experiments on rotation of pearl millet with clusterbean showed that cereal – legume rotation gave better yields than monocropping of pearl millet. Under irrigated conditions, wheat, mustard, cumin are taken after pearl millet, clusterbean or moong bean. Cumin yields were higher when taken after pearl millet rather than after legumes.

The crop-growing period in western Rajasthan varies from <6 to 14 weeks depending upon rainfall and type of soils. Pulses were found to be more drought-tolerant than

pearl millet. The yields of pearl millet declines substantially, if sowing is delayed beyond third week of July. Under delayed onset of monsoon rains clusterbean, moong bean and moth bean deserve preference to obtain greater harvest.

Water management: Evapotranspiration requirements of crops depends on season and maturity period of varieties. Such requirements were worked out in details for a range of crops that are widely grown in arid regions enabling farmers to make a suitable choice of crops and varieties in different areas with variable rainfall and water availability. Broadly the seasonal water requirement of unstressed crops were found to be 320 to 410 mm for pearl millet; 290 to 340 mm for moong bean, 250 to 350 mm for moth bean, 300 to 320 mm for cowpea and 425 to 800 mm for clusterbean.

Deficit irrigation (20 to 50% reduction in irrigation amount) resulted in higher water productivity of groundnut and wheat. This approach offers scope for extending irrigation to larger areas. A single life-saving irrigation to pearl millet was found to increase grain yield by 60%. Life-saving irrigation to clusterbean, even with poor quality water, increased yield significantly under drought condition.

Sprinkler irrigation applies water more efficiently compared to flood irrigation and it was found suitable for most field crops even in undulating fields. Drip irrigation is most effective but requires initial investment. The CAZRI was one of the earlier institutes to recognize this and initiated work of drip irrigation in 1972 (Fig. 4). A technique of double-row planting with single lateral was developed that reduced the capital cost and water use substantially while there was very less adverse effect on yield of vegetable crops like bottle-guard, watermelon, muskmelon etc.

Nutrient management: Fertility of native soils being very low, nutrient management for various crops, cropping system and farming system is critical for obtaining good yields. Therefore, the response of major

crops to various nutrients was studied in detail. Rainfed pearl millet responded well up to 80 kg N ha⁻¹ in good rainfall years, but during low and moderate rainfall years 40 kg N and 40 kg P₂O₅ ha⁻¹ proved sufficient. Yields of moong bean, clusterbean and moth bean were higher with the application of 20 kg N and 40 kg P₂O₅ ha⁻¹. Application of organic manures like farmyard manure showed beneficial and synergistic effect with inorganic fertilizers on crop yields. Inoculation with biofertilizers like *Rhizobium* and *Azotobacter/Azospirillum* with organic manure and/or low doses of N and P, improved the yield of arid crops by 10 to 15%.

Mixing element sulphur (S) with urea and sulphur coated urea reduced volatilization losses of N resulting in improved crop yields and higher nutrient use efficiency. Organo-mineral fertilizer, prepared from locally available feldspar, proved to be an excellent source of continuous K supply during cropping season in pearl millet, moongbean, mustard and wheat. Nano-particles of Fe, Zn and Cu were synthesized. The crop yields were found to increase with application of nano-Fe and Zn.

Phosphatase and phytase releasing fungi (*Chaetomium globosum*, *Curvularia lunata*, *Emmericella rugulosa* and *Trichoderma harzianum*) and bacteria (*Bacillus coagulans* and *Alcaligenes faecalis*) were identified to mobilize native soil phosphorus to the tune of 45 to 125 kg P₂O₅ ha⁻¹ resulting in 13 to 28% additional yields of rainfed crops.

Tillage: Several interventions in tillage were tested and evaluated. Results indicated that one preparatory tillage would be a minimum requirement for satisfactory harvest of crops in light textured soils. Deep tillage was found to improve soil moisture storage and resulted in increased yields of pearl millet and legumes over conventional tillage. However, the fields needs to be prepared after rainfall, as summer ploughing is most likely to increase soil erosion.

Soil crust formation after light rains is a common phenomenon in aridisols resulting in reduced seedling

emergence of pearl millet. Application of 5 to 10 tonne farmyard manure ha⁻¹ in furrows after sowing was effective in reducing soil crust strength and increasing emergence of seedlings.

Pest management: Pests, diseases and weeds caused significant decline in crop yields necessitating the need of control measures. Soil solarization for about two weeks during May-June was found to be very effective against soil-borne diseases and reduced weed population. Incorporation of mustard pod residues (2.5 tonne ha⁻¹) in soil during summer followed by one irrigation was effective against *Fusarium* wilt as it substantially reduced fungal population. Bio-formulations Maru Sena 1 prepared from *Trichoderma harzianum* and Maru Sena 3 prepared from *Bacillus firmus* were found to be effective against dry root rot in clusterbean and wilt in cumin. Effective control measures were developed to revive dying trees of *P. cineraria* due to *Ganoderma* infestation.

Studies on rodent ecology helped in identifying optimum seasons for their control and effective ways of bait placement. Effective bait formulations for rodent control were identified.

Weed control schedules in *kharif* and *rabi* crops through chemical and/or cultural methods were developed. Application of fluchloralin or pendimethalin (0.5 kg ha⁻¹) along with one-hand weeding at 30 days after sowing was very effective for weed management in moong bean and mustard.

Stress tolerance: Physiological and biochemical basis of drought tolerance in pearl millet, mustard, cumin and *isabgol* genotypes helped in minimizing the losses due to water stress. Planting of early and late-maturing genotypes together, often termed as geno-cropping, proved effective in stabilizing yields of clusterbean and moth bean under variable drought conditions. Low N fertilizer dose (20 kg ha⁻¹) was found to alleviate the adverse effects of drought and salinity. Seed treatment with thiourea (500 ppm) or its spray (1,000 ppm) during vegetative

growth increased the yield of arid legumes, both under normal and low rainfall situations. Spray of salicylic acid (1.5 mM solution) also enhanced drought tolerance.

Stems of *senna* (*Cassia angustifolia*), a widely cultivated medicinal plant in arid zone, was found to contain plant growth promoters. One spray of extract of *senna* residue (a byproduct) improved the growth and yield of pearl millet and wheat. Foliar spray of ZnSO₄ (0.125 to 0.25%) on crops was found effective in alleviating substantially the adverse effect of thermal stress.

Arid horticulture: Horticultural crops are extremely vital in arid production environments due to their resilience to stress conditions and in achieving high water productivity, in addition to their significant role in enhancing income and nutritional security. The ICAR-CAZRI took note of it in early 1970s and introduced several genetic accessions of arid fruits like *ber* (*Ziziphus mauritiana*), pomegranate (*Punica granatum*), *gonda* (*Cordia myxa*), *karonda* (*Carissa carandas*), *aonla* (*Emblica officinalis*), *bael* (*Aegle marmelos*) and date palm (*Phoenix dactylifera*). Among them, improved varieties of *ber* like Gola, Seb, Umran and Mundia made a huge impact in arid regions across country (Fig. 5). A *ber*-budding technique was perfected which boosted a large number of *ber* nurseries that supplied the budded seedlings to Gujarat, Maharashtra, Madhya Pradesh, Andhra Pradesh and Karnataka. The Institute has also standardized the techniques of optimum plant spacing (6 × 6 m²), nutrient management, rejuvenation of old *ber* orchards, control of *ber* fruit fly, post-harvest technology etc. Recognizing huge success of *ber* in Indian arid regions, the crop was also introduced in Africa where it is spreading and making a significant impact.

Pomegranate (*Punica granatum*) cultivar Jalor-seedless was found to be suitable for this region, and its propagation technique, optimum spacing (5 × 5 m²) and agro-techniques were standardized. Irrigation through drip system at flowering and fruiting stages



Fig. 5. A bountiful harvest of early maturing *ber* variety 'Gola'

considerably increased its yield and reduced fruit cracking. Similarly, high-yielding cultivars of *bael* (*Aegle marmelos*) viz., Dhara Road and Faizabadi Local and *aonla* (*Emblica officinalis*) were identified and their propagation technique through budding was standardized.

Agro-biodiversity and crop improvement

Arid ecosystem is unique and extremely diverse for its flora consisting of grasses, bushes, shrubs, multipurpose trees and crops, which is maintained in form of landraces, cultivars, genetic stocks, germplasm and wild and weedy relatives. Crops and plants of arid region were developed diverse and unique adaptive strategies to survive in extreme environments.

Improved varieties/genotypes of grasses: The Institute screened a large number of promising strains of desert grasses viz. *Lasiurus indicus*, *Cenchrus ciliaris*, *Cenchrus setigerus*, *Dichanthium annulatum* and *Panicum antidotale* (Fig. 6). The efforts gave a number of improved varieties of grasses like CAZRI-75 (Marwar Anjan), CAZRI-357 and CAZRI-358 of *Cenchrus ciliaris*; Marwar Dhaman (CAZRI-76), CAZRI-1 and CAZRI-296 of *C. setigerus*; CAZRI-318, CAZRI-319, CAZRI-30-5 of *Lasiurus indicus*; CAZRI-347 of *Panicum antidotale*. The improved strains of pasture legumes like CAZRI-144, CAZRI-1462 and CAZRI-1258 of *Lablab purpureus*; CAZRI-453, CAZRI-466 and CAZRI-468 of *Clitoria ternatea* were identified.



Fig. 6. A view of germplasm block of perennial grasses with adaptation to arid environments

Selection and propagation of suitable trees: Several exotic tree species from iso-climatic regions of the world and fast-growing native tree and shrub species were introduced by the institute. In arid climate, *Acacia tortilis*, *A. nilotica*, *A. albida*, *A. bivenosa*, *A. ampliceps*, *A. eripoda*, *Eucalyptus camaldulensis*, *E. terminalis*, *Colophospermum mopane*, *Dichrostachys mutans*, *P. alba*, *P. chilensis*, *Hardwickia binata* and *Pongamia pinnata* showed good performance. Trees of *Prosopis cineraria*, *Tecomella undulata*, *Acacia albida*, *A. senegal*, *A. nilotica* and *A. tortilis* were identified. Progeny trials and seed orchards of these species were established. Genetic polymorphism in natural populations and pollination behaviour was also investigated using isoenzyme and molecular markers.

Prosopis juliflora is a very fast growing tree but had little uses. It was used as rootstock, and *P. alba* and *P. pallida* scions were grafted on it through cleft-grafting technique. The technique was perfected and standardized for nursery conditions. Air layering of *Prosopis cineraria* was found useful for its vegetative propagation. Macro-propagation technique for *P. cineraria* was developed and exotic *Prosopis* spp. were successfully propagated through vegetative means. Protocols for *in-vitro* micropropagation of date palm using apical meristem from off shoots for production of callus, *P. cineraria* using shoot and root segments for production of primary/secondary shoots and *Simmondsia chinensis* using coppice shoots as explant were developed.

Crop varieties: The traditional cultivars and landraces of native crops were evolved over many generations

under natural selection in arid environments that included severe drought and high temperature conditions. They were also selected by farmers for preferred traits and high productivity. Consequently, such landraces possess better adaptation to stress environments and make an excellent genetic material for understanding the mechanism of adaptation to abiotic stress conditions and are sources of native genes for enhancing adaptation. More than 1,000 accessions of arid crops were collected, characterized and conserved in the National Gene Bank of NBPGR so that they are available for posterity. Selected landraces were made base material for further selection resulting in development of new stress-adapted cultivars like CZP-9802 and CZ-IC-923 of pearl millet; CAZRI-Moth-1, CAZRI-Moth-2, CAZRI-Moth-3 of moth bean; Maru Guar of clusterbean, and Maru Kulthi-1 of horsegram. The local germplasm material was also used for understanding the yield-formation process under stress conditions and was strategically utilized for introgression into elite genetic material so as to amalgamate stress adaptation with high productivity.

The Institute produced quality seed of improved varieties of crops and grasses and saplings of trees and fruit crops to cater to the increasing demand of the farmers of the region and other stakeholders.

Livestock and grassland management

Livestock is very important component of mixed crop-tree-grass-livestock farming system in arid regions and its major role is to enhance the resilience of system to stressful environments and to provide reliable income in extreme drought years when other components largely fail. Due to this reason, the livestock:human ratio is higher in arid areas than in other areas. There was 120% increase in livestock population from 13.7 million in 1961 to 30.2 million in 2012. The maximum increase (308%) was recorded in the population of buffalo, followed by 273% in goats, 58% in sheep, and 41% in cattle population

during this period. Sustaining such a huge population of livestock was the greatest challenge in arid regions given low biomass productivity of arid lands and high degree of land degradation.

Livestock breeds: The arid regions have a genetic wealth in stress-adapted breeds of cattle (Tharparkar, Kankrej and Rathi); of buffalo (Mehsana, Jaffarabadi, Banni and Surti); of sheep (Chokla, Nali, Magra, Marwari, Jaisalmeri and Pugal); of goat (Marwari, Parbatsari, Kachchhi, Sonadi and Malpura) which can give fairly good milk yields even under harsh arid conditions with poor quality fodder and also responds well to good management and feeding. Thermal stress is common in hot arid environment and native breeds were found to have favourable physiological, haematological and biochemical responses to help them survive in harsh environment. Shelters were designed that protected animals from high temperatures during summer and cold temperatures during winter leading to better growth and milk yield.

Balanced feeding: Multinutrient feed blocks for livestock were prepared using low-cost ingredients like wheat bran, *guar korma*, jaggery, urea, common salt and mineral mixture. Feeding the multinutrient feed blocks to cows and buffaloes increased their daily milk yield by 10 to 25% and improved their reproductive performance. *Prosopis juliflora* pods were used as ingredient of multinutrient feed blocks to further reduce the cost. It includes *P. juliflora* pods' powder, clusterbean *korma*, sesame seed-cake, wheat-bran, maize grain, common salt, mineral mixture as per requirement. Feed block production units were also established in villages.

Similarly, multi-nutrient mixture was prepared for sheep and goats that comprised of molasses, urea, common salt, vitamin-mineral mixture, dolomite, wheat bran, clusterbean meal and organic binder. It showed beneficial effects in body weight gain, milk and wool production, and early maturity (puberty) in ovines.

Tumba (*Citrullus colocynthis*) seed-cake containing 16 to 22% protein and was found to be a healthy non-conventional feed for heifer. Digestibility of *P. cineraria* leaves was improved through heating leaves with 0.5 N aqueous solution of sodium bicarbonate to remove tannin.

Grassland management: Controlled grazing and reseedling with high-yielding varieties/strains of perennial grasses like *Lasiurus indicus*, *Cenchrus ciliaris*, *C. setigerus*, *Dichanthium annulatum*, *Panicum antidotale* and *Sehima nervosum* on was found most suitable for increasing forage production from degraded rangelands. The carrying capacity of grasslands was worked out for their sustenance on long-term basis. Growing of top-feed species like *Prosopis cineraria*, *Ziziphus nummularia*, *Dichrostachys nutans*, *Colophospermum mopane* etc. in silvi-pastoral system further enhances the productivity and carrying capacity of the rangelands. Contour furrows, contour bunds and contour trenches were found to increase moisture conservation in grassland resulting in greater forage yield. Regeneration of *sewan* (*Lasiurus indicus*), was found to be better after contour furrows were created.

Thornless cactus (*Opuntia ficus-indica*) was introduced as non-conventional fodder resource which provides green fodder even during April-June, the driest period of year. Supplementation with *Azolla* also showed positive results in enhancing growth and milk yield in cattle.

The Institute takes pride in developing, since inception, 52 rangeland areas, where it conducted elaborate grazing studies and demonstrated the benefit of range management. After developing these areas, CAZRI handed them over to the State Government of Rajasthan.

Value addition to augment income

A number of value-added products were developed from plant and animal produces. The Institute developed a simple technique of ethephon injection for increasing gum exudation (0.3 to 0.5 kg tree⁻¹) from *kumat* (*Acacia senegal*) trees. About 20,000 injections were sold

every year. A large number of farmers of Barmer, Jodhpur, Nagaur, Jhunjunu and Pali districts adopted this gum induction technology at a large-scale fetching them an additional income of ₹ 50 to 60 lakh/year since 2008.

Compounds of industrial values were identified and isolated from unexploited arid zone plants. These included diosgenin from seeds of *Balanites aegyptiaca*, candelilla wax from *Euphorbia antisiphilitica*, rotenone from *Tephrosia villosa*, triacontanol from *P. cineraria* and *P. juliflora*, scopolamine from *Datura innoxia*, cineole from *Eucalyptus viridis*, essential oils from the leaves of *Cymbopogon martini* and oleoresins from *Commiphora wightii*.

A range of products like shampoo, crake-cream, moisturizer, jelly, candy, etc. were prepared from *Aloe vera*. Recipes were standardized for preparation of squash, jam, jelly from *ber*, *anardana* from pomegranate; jam, preserve and shreds from *aonla*; squash, preserve and jam from *bael*; squash, jam, and dehydrated fruits of *peelu* (*Salvadora oleoides*); edible products from *tumba* (*Citrullus colocynthis*); squash, chutney, jam from *kachra* (*Cucumis melo*) and *kachri* (*Cucumis callosus*); biscuits, flakes from pearl millet etc. Similarly, milk-products like cheese, *kesar kulfee* (a variety of ice cream) and whey drink were prepared from goat milk.

Farm mechanization and renewable energy

A 3-row-furrow (6-row), tractor-operated seed-cum-fertilizer drill, with a provision for seed-pressing device, was designed and developed for sowing the crops on ridges and conservation of moisture in furrows. A manual farmyard manure applicator, a *ber*-grader, a cumin-grader and improved *kassi* (hand hoe) were developed. Polyhouses of different sizes and materials were designed and developed. A passive cool chamber was developed on the principle of evaporative cooling for storing vegetables, fruits, milk etc. for the areas where electricity supply is uncertain.

The Institute developed a large number of solar thermal and solar



Fig. 7. Agro-voltaic system having solar panels and crops grown in inter-panel space

photo-voltaic (PV) devices like collector-cum-storage type solar water heater, solar water heater-cum-still, solar water heater-cum-steam cooker, solar cabinet dryer with auto-regulation of temperature, phase change material-based dryer, solar cooker, animal feed solar cooker, solar candle making machine, solar desalination device, solar water purifier etc. PV devices like shoulder-mounted solar PV duster for dusting insecticide powder, solar PV winnower cum dryer, solar PV mobile unit etc. were developed. A solar PV pump-operated drip irrigation system was also developed. Several of them were propagated through various government-sponsored schemes and Public-Private Partnership.

An Agri-Photo-Voltaic System (AVS) of 105kW capacity was developed in the campus with the objective of making best use of land resources through PV-based electricity generation, rainwater harvesting and crop production. It will help in developing suitable models for harnessing abundantly available solar energy in arid zone for electricity generation and crop production (Fig. 7).

Capacity building, extension and evaluation

The Institute strengthened National Demonstration Programmes, Front-Line Demonstration, Operational Research Project, Lab-to-Land Programme, Training and Visit, Desert Development Programme for farmers' welfare and also included Institute Village Linkages Programme for dissemination of technologies.

Education and training for technology transfer: The Institute conducted numerous national and international training courses since its inception including specialized international training courses sponsored by UNESCO, ESCAP, FAO, US-AID etc. Frequent training courses were conducted for personal of state-line departments. The extension wing of the Institute and Krishi Vigyan Kendras imparted training on various aspects to farmers, rural women and unemployed youth. Over 250 villages in western Rajasthan reached directly by the Institute for on-farm demonstration of technologies. Bi-weekly agro-met advisory bulletins were issued for farmers since 1998 so that they can make best use of likely favourable weather conditions or to minimize losses due to adverse weather.

Agricultural Technology Information Centre (ATIC) is a single-window platform to provide scientific agro-advisories and improved technologies to farmers and caters to the needs of the farming community and others stakeholders. The Institute organizes regular *Kisan Mela* (Farmers' Fare), field days and demonstration camps in villages as well as at its premises. A large number of farmers visited ATIC, experimental areas, crop cafeteria, organic farm, protected cultivation site etc. every year.

Socio-economic studies: To understand the special problems and needs of nomads, pastoral communities, schedule tribes, and farm-women to name a few socio-economic innovations were done. Adoption behaviour of various categories of farmers and for different technologies were studied.

Impact

A large number of need-based technologies were developed and disseminated by the institute for overall sustainable development of

arid agriculture. Impact of some of such technologies was quantifiable in increased productivity of crops in arid regions as such data is reported on annual basis by government departments. Moreover, it should also be recognized that increased productivity of crops is the final outcome of multiple interventions like new varieties, water management, weed control, cropping sequence, nutrient management, disease control that might be undertaken on the behest of various departments. Nonetheless, there is very strong impact of improved agro-techniques on productivity of five most important crops of arid zone. A tremendous increase of 254% in yield of pearl millet, 179% in moong bean, 144% in sesame, 98% in clusterbean and 93% in moth bean were recorded from 1974 to 2016.

About 1,00,000 saplings of various horticulture and forestry species were raised in the institute nursery every year which are purchased mostly by farmers. A large quantity of seed of improved varieties of legumes are also sold.

Cost-benefit ratio analyses of technologies like sand-dune stabilization, shelterbelt plantation, wind erosion control, watershed management, water harvesting, conservation of agro-biodiversity, farm mechanization, renewable energy etc showed that the technologies are cost-effective, though some of the technologies have long gestation period. Moreover, there exists no economic indicators for assessing the quantifiable impact of many such technologies. However, there were several ecosystem services that are provided by such interventions.

There was increase in net sown area in arid Rajasthan from 8.36 m ha in 1960-61 to 11.2 m million ha in 2014-15. Number of dust storms reduced from 17 in 1966 to 2.5 in 2000. There was decrease in wind erosion affected area from 75% in

1990 to 73% in 2013. Similarly sand dunes cover was reduced from 54% in 1990 to 48% to 2013. Sand dune stabilization technology spread in about 4 lakh ha and about 800 km length for shelterbelt plantation was achieved in 1960s.

The way forward

The CAZRI is the only institute in the country that is addressing a myriad of inter-connected issues like assessment and management of natural resources; devising sustainable farming systems, utilizing agro-biodiversity; managing livestock and grassland; augmenting farmers' income, promoting renewable energy in farming and social life; and building capacity of stakeholders in the arid production environment in an all-inclusive way.

Consequently, several technologies were also developed for development of agriculture in arid regions. However, the dynamic state of natural resources like land, soil, water, climate, vegetation as well as the changing needs of farmers and food habits and demands of people, necessitate continuous refinement/development of technologies to suit the emerging situations.

SUMMARY

Development of technology alone won't suffice unless there is serious involvement of various stakeholders adequately backed up by development of appropriate infrastructure along with proper policy formulation and implementation for the holistic development of the region.

The Institute envisioned 'a greener, climate resilient arid land with well-managed and sustainable agriculture that provides improved livelihood options and conserves scarce natural resources'.

¹Director, Corresponding authors' e mail: opyadav21@yahoo.com

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