हर कदम, हर डगर
किसानों का हमसफर
भारतीय कृषि अनुसंधान परिषद

Agrisearch with a human touch

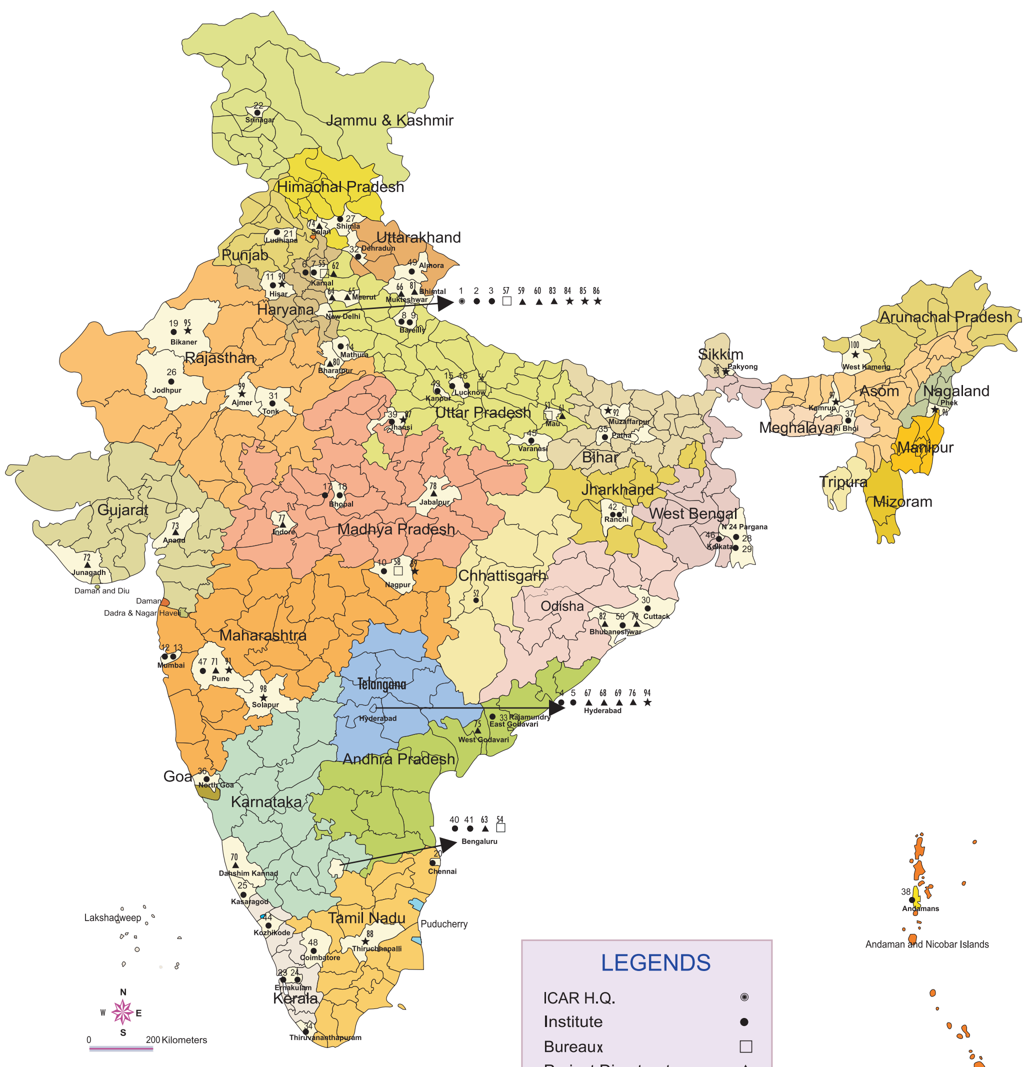
# Vision 2050

Central Arid Zone Research Institute

Indian Council of Agricultural Research

# INDIAN COUNCIL OF AGRICULTURAL RESEARCH

## Institutes, Bureaux, Directorates and National Research Centres




### LEGENDS

- ICAR H.Q.
- Institute
- Bureaux
- Project Directorate
- National Research Centre

• 64 Research Institutes • 6 Bureaux • 15 National Research Centres • 15 Project Directorates

# INDIAN COUNCIL OF AGRICULTURAL RESEARCH

## Agricultural Universities


### LEGENDS

- State Agricultural Universities
- Central Universities with Agricultural faculties
- Central Agricultural Universities
- Deemed Universities

# Vision 2050

Central Arid Zone Research Institute
(Indian Council of Agricultural Research)
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# संदेश

भारतीय सभ्यता कृषि विकास की एक आधार रही है और आज भी हमारे देश में एक सुदृढ़ कृषि व्यवस्था मौजूद है जिसका राष्ट्रीय सकल घरेलू उत्पाद और रोजगार में प्रमुख योगदान है। ग्रामीण युवाओं का बड़े पैमाने पर, विशेष रूप से शहरी क्षेत्रों में प्रवास होने के बावजूद, देश की लगभग दो-तिहाई आबादी के लिए आजीविका के साधन के रूप में, प्रत्यक्ष या अप्रत्यक्ष, कृषि की भूमिका में कोई बदलाव होने की उम्मीद नहीं की जाती है। अतः खाद्य, पोषण, पर्यावरण, आजीविका सुरक्षा के लिए तथा समावेशी विकास हासिल करने के लिए कृषि क्षेत्र में स्थायी विकास बहुत जरूरी है।

पिछले 50 वर्षों के दौरान हमारे कृषि अनुसंधान द्वारा सृजित की गई प्रौद्योगिकियों से भारतीय कृषि में बदलाव आया है। तथापि, भौतिक रूप से (मृदा, जल, जलवायु), बायोलोजिकल रूप से (जैव विविधता, हॉस्ट-परजीवी संबंध), अनुसंधान एवं शिक्षा में बदलाव के चलते तथा सूचना, ज्ञान और नीति एवं निवेश (जो कृषि उत्पादन को प्रभावित करने वाले कारक हैं) आज भी एक चुनौती बने हुए हैं। उत्पादन के परिवेश में बदलाव हमेशा ही होते आए हैं, परन्तु जिस गति से यह हो रहे हैं, वह एक चिंता का विषय है जो उपयुक्त प्रौद्योगिकी विकल्पों के आधार पर कृषि प्रणाली को और अधिक मजबूत करने की मांग करते हैं।

पिछली प्रवृत्तियों से सबक लेते हुए हम निश्चित रूप से भावी बेहतर कृषि परिदृश्य की कल्पना कर सकते हैं, जिसके लिए हमें विभिन्न तकनीकों और आकलनों के मॉडलों का उपयोग करना होगा तथा भविष्य के लिए एक ब्लूप्रिंट तैयार करना होगा। इसमें कोई संदेह नहीं है कि विज्ञान, प्रौद्योगिकी, सूचना, ज्ञान-जानकारी, सक्षम मानव संसाधन और निवेशों का बढ़ता प्रयोग भावी वृद्धि और विकास के प्रमुख निर्धारक होंगे।

इस संदर्भ में, भारतीय कृषि अनुसंधान परिषद के संस्थानों के लिए विजन-2050 की रूपरेखा तैयार की गई है। यह आशा की जाती है कि वर्तमान और उभरते परिदृश्य का बेहतर रूप से किया गया मूल्यांकन, मौजूदा नए अवसर और कृषि क्षेत्र की स्थायी वृद्धि और विकास के लिए आगामी दशकों हेतु प्रासंगिक अनुसंधान संबंधी मुद्दे तथा कार्यनीतिक फ्रेमवर्क काफी उपयोगी साबित होंगे।

**( राधा मोहन सिंह )**

केन्द्रीय कृषि मंत्री, भारत सरकार

# Foreword

Indian Council of Agricultural Research, since inception in the year 1929, is spearheading national programmes on agricultural research, higher education and frontline extension through a network of Research Institutes, Agricultural Universities, All India Coordinated Research Projects and Krishi Vigyan Kendras to develop and demonstrate new technologies, as also to develop competent human resource for strengthening agriculture in all its dimensions, in the country. The science and technology-led development in agriculture has resulted in manifold enhancement in productivity and production of different crops and commodities to match the pace of growth in food demand.

Agricultural production environment, being a dynamic entity, has kept evolving continuously. The present phase of changes being encountered by the agricultural sector, such as reducing availability of quality water, nutrient deficiency in soils, climate change, farm energy availability, loss of biodiversity, emergence of new pest and diseases, fragmentation of farms, rural-urban migration, coupled with new IPRs and trade regulations, are some of the new challenges.

These changes impacting agriculture call for a paradigm shift in our research approach. We have to harness the potential of modern science, encourage innovations in technology generation, and provide for an enabling policy and investment support. Some of the critical areas as genomics, molecular breeding, diagnostics and vaccines, nanotechnology, secondary agriculture, farm mechanization, energy, and technology dissemination need to be given priority. Multi-disciplinary and multi-institutional research will be of paramount importance, given the fact that technology generation is increasingly getting knowledge and capital intensive. Our institutions of agricultural research and education must attain highest levels of excellence in development of technologies and competent human resource to effectively deal with the changing scenario.

Vision-2050 document of ICAR-Central Arid Zone Research Institute (CAZRI), Jodhpur has been prepared, based on a comprehensive assessment of past and present trends in factors that impact agriculture, to visualise scenario 35 years hence, towards science-led sustainable development of agriculture.

We are hopeful that in the years ahead, Vision-2050 would prove to be valuable in guiding our efforts in agricultural R&D and also for the young scientists who would shoulder the responsibility to generate farm technologies in future for food, nutrition, livelihood and environmental security of the billion plus population of the country, for all times to come.

**(S. AYYAPPAN)**
Secretary, Department of Agricultural Research & Education (DARE)
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# Preface

Inhabitants of the Indian arid regions had been practicing subsistence farming (arable and pastoral) for ages and were able to maintain a balance between their needs and fragile natural resources. Population density was very low and long fallowing for grazing the animals and to restore soil fertility was common practice. However, these regions, particularly the hot arid regions, have witnessed tremendous changes since independence of the country. Population pressure (human and livestock) has increased several folds. The land use pattern has changed almost entirely in irrigated areas after introduction of major canal systems like Indira Gandhi Nahar Priyojayana (IGNP), Bhakra, Satluj Yamuna Link Canal, Narmada canal as well as through boring of tube wells after rural electrification. Practice of long fallowing has decreased in rainfed areas and herders/graziers are facing increasing difficulty in maintaining their herds/flocks due to shrinking grazing resources. No doubt, the production and productivity of most of the crops, fruits, vegetables, etc. has increased substantially due to increase in cropping intensity, irrigation facilities in some areas and availability of better inputs like seed, fertilizer, pesticides, farm machinery and tools, etc. But injudicious use of land, water and inputs has taken its toll. Introduction of high water requiring crops like sugarcane, cotton, groundnut and chillies in IGNP command area has created problem of water-logging and secondary salinization. Groundwater level is depleting at an alarming rate in tube well irrigated areas and in some parts of Banaskantha (Gujarat), Jhunjhunu and Pali (Rajasthan) districts, it is no more economically viable to pump it out. Such practices are just unsustainable.

I have great appreciation for the farmers and agricultural scientists, past and present, who worked together, blended traditional wisdom and modern agricultural technologies and demonstrated in real world situations (field conditions) that sustainably higher and economically viable land, water, crop and animal productivity can be achieved without overexploitation of natural resources. CAZRI has adopted holistic approach since its inception. An array of technologies like sanddune stabilization, wind erosion control, rehabilitation of wastelands, grassland improvement, watershed development, water management, arid land farming, arid horticulture, alternate land use systems, pest management, solar devices, etc. has been developed and demonstrated.

Coming 4-5 decades are going to be the most challenging time for arid agriculture. Per capita agricultural land is decreasing with little scope of horizontal expansion. Cost of labour and energy is increasing while their availability for agricultural operations is decreasing. Global warming is most likely to have adverse effect on plant and animal productivity and may further aggravate the situation through altered pest, diseases and weed composition; extreme weather events or change in rainfall amount/distribution. Despite the severe limitations, arid agriculture has to meet the additional food demand of increasing population (till it stabilizes by around 2050-70), in addition to address the issue of hidden hunger and increasing demand for quality food like milk, meet, eggs, fruits and vegetables. Demand for feed and fodder will also surge due to increase in demand of animal products and practice of stall feeding.

Achievement of such a daunting task needs vision and road map besides resources and policy support. It may be possible only through convergence and most efficient utilization of resources available with the institutes, departments, agencies, etc. involved in rural and agricultural development. CAZRI has appreciation of such an approach and it has been working with different institutes/organisations and line departments of state governments. Generation/availability of technologies alone do not guarantee increased productivity. Farmer is the ultimate decision maker. Without this understanding and appreciation of long-term advantages of technology adoption; no major breakthrough can be achieved. We thank the farmers of the region, who worked with our scientists in development and refinement of agro-techniques suitable for their micro-farming requirements as well as socio-economic conditions and demonstrated the benefits of the institute's technologies to other farmers. Such encouraging experiences gave us the wisdom of working-with-farmers rather than working-for-farmers. The institute will strengthen this approach in its future endeavours of applied research.

We thank Honourable DG, DDG (NRM), ADG (Agronomy), Chairpersons and members of Research Advisory Committee (RAC) and Institute Management Committee (IMC) for critical review of the Vision 2050 draft and their valuable inputs and suggestions for its improvement. I thank the Heads of Divisions and RRSs and scientists of the institute for useful inputs to the vision document.

I hope this document will be a reminder of the complexities and challenges for agriculture in the hot and cold arid regions as well as opportunities in near future. Through the vision document, we rededicate ourselves to meet the challenging task of achieving high and sustainable productivity of arid agriculture; in close association with farmers and cooperation with sister research organisations and line departments of the states; for *Khushhali* (wellbeing) of the farmers and satisfaction of the consumers of agricultural commodities.

Director

# Contents

# Context

INDIAN Council of Agricultural Research (ICAR), New Delhi, the apex Research and Development (R&D) organization for agriculture and allied sciences is responsible for developing technologies for enhancing national food, fodder, fuel and fibre productivity to meet the current and future requirements. The Central Arid Zone Research Institute(CAZRI), Jodhpur has strived hard for over five decades for arid land management and made a significant mark in this direction. However, next four decades will be very crucial in view of the changing demographic and climatic scenarios. The present compilation attempts to outline the priorities of the institute up to 2050.

About 15% of the earth's surface is covered by deserts (19.0 million square kilometers). Desertification, the degradation of drylands due to factors like climatic variations and human activities, is one of the most serious environmental challenges of the day. It was against this backdrop that the UN General Assembly declared 2006 to be the International Year of Deserts and Desertification. Scarce and erratic rainfall, extremes of climate, coarse textured soils, depleting groundwater and other natural resources pose a serious challenge to arid production systems. Water scarcity is major problem for sustainable agriculture in deserts and creation of irrigation facilities has generated new problems. Irrigated portions of deserts in China, India, and Pakistan face declining yields due to increasing salinity. Impending climate change scenario is further likely to accentuate the problems globally. The deserts are, however, rich in faunal and floral diversity, solar and wind power, minerals, etc. Cold arid regions too present similar scenarios. The *Thar* Desert is one of the most populated deserts of the world, both in terms of human and livestock population. Therefore, there is an urgent need to develop a sound perspective planning with a view that hot and cold arid regions, with their unique strengths and inherent weaknesses, should strive to contribute maximum to the national food security and export earnings.

CAZRI has the distinction of being one of the first institutes of its kind in the world devoted to arid zone research and development. The institute made a humble beginning in 1952 when Government of India initiated Desert Afforestation Research Station at Jodhpur to carry out research on sanddune stabilization and establishment of shelter belt plantations to arrest wind erosion; as it was then apprehended that desert is spreading towards east. It was reorganized in 1957 as Desert Afforestation and Soil Conservation Station and finally in its present form 'Central Arid Zone Research Institute' in 1959 on recommendation of the UNESCO (United Nations Educational, Scientific and Cultural Organisation) Expert, Dr. C.S. Christian of Commonwealth Scientific and Industrial Research Organisation, Australia. In 1966, the institute was brought under the administrative control of ICAR.

CAZRI has five Regional Research Stations (RRSs) at Pali, Jaisalmer and Bikaner in Rajasthan; Kukma-Bhuj in Gujarat and a recently established RRS at Leh in Jammu and Kashmir. It has five field areas for range management studies. So far, the major emphasis of the institute has been on hot arid regions spread mainly in Rajasthan, Gujarat, Punjab and Haryana. Broadening its area of activity in arid regions of peninsular India a Hot Arid Network was launched by the institute in collaboration with State Agricultural Universities (SAUs) in Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu during XI Plan. Similarly, the institute initiated a Cold Arid Network in collaboration with four institutes located in J&K and Himachal Pradesh to focus on the issues related to cold arid region. The institute also hosts two All India Network Projects (AINPs) on Arid Legumes and Rodent Control with their centres spread in many institutes and SAUs located in different agro-ecological regions of the country.

During the last five decades of its existence, CAZRI has carried out systematic research on understanding and managing the region's natural resources, sustainable farming systems, improvement in plant resources, especially the crop plants, livestock production and management and use of alternate energy resources. Several need-based, cost effective technologies like sanddune stabilization, wind erosion control, water management, grassland improvement, watershed development, rehabilitation of wastelands, arid land farming, arid horticulture, alternate land use strategies, pest management, solar devices, etc. have been developed and transferred to farmers and other stakeholders. The institute has evolved technologies and strategies for combating drought and desertification. It has developed close liaison with several national and international organizations and has made major strides in providing advisories and consultancies to many agencies in India and abroad. Besides, CAZRI is a major destination for capacity building activity on arid zone development for scientists, policy planners and extension officials. Through its extension wing and Krishi Vigyan Kendras (located at Jodhpur, Pali and Kukma-Bhuj) the institute is in direct touch with farmers, state government officials, NGOs and other stakeholders through regular trainings and demonstrations. This institute has the rare distinction among ICAR institutes, in having a full-fledged section on renewable energy and has developed many solar energy based gadgets/devices, like solar animal feed cooker, dryers, water heaters, candle making device, cool chambers, etc., which are finding place in rural households. CAZRI has strengthened its efforts on post-harvest technology and developed many value added products from plants and animals of the arid region.

❑

# Challenges

MAJORITY of people in India depend on agriculture but the share of agriculture in Gross Domestic Product (GDP) is declining steadily. Since 1990s, India has been able to maintain high economic growth. However, food demand has not been growing at the rates expected from the high economic growth and the high prevalence of unsatisfied food needs. It has currently the same low calorie consumption (~2300 kcal/person/day) as it had 25 years ago, a phenomenon often referred to as the 'Indian paradox' (FAO, 2012). Long term projections indicate that food demand in India will increase significantly because of increasing population, low current consumption levels, undernourishment and the prospect of continuation of sustained income growth. FAO (2012) estimated that calorie consumption in India will be around 2825 kcal/person/day in 2050. The major challenges to meet the increased food requirements in future are summarised below:

**Increasing population pressure:** The ever-increasing human and animal population is likely to have much higher demands for food, fibre, feed and fodder and exert great pressure on already scarce natural resources. Human population of India has increased from 361.6 million in 1951 to 1210.19 million in 2011. However, the growth rate of population has declined from 22.5% per decade in the 1970s to 17.64% in the last decade (2001-2011). United Nations (2012) estimated that the population of India is likely to stabilize at around 1650 million in 2060s. The human population in western Rajasthan has also seen a very high growth of >250% during 1961-2011. It is estimated to reach 41 m in next 20 years from 28.15 m in 2011. Increase in purchasing power is creating higher demand for quality food like fruits, vegetables, milk and other dairy products, egg, poultry, fish, meat, etc. Direct consumption of coarse cereals for food is likely to decrease, but the demand for use as feed source for cattle, poultry and fish will increase.

As per the livestock census of 2012, arid Rajasthan harbours 30.18 million livestock comprising of 20.5% cattle, 13.1% buffalo, 22.8% sheep, 42.4% goat, 0.9% camel and others such as equines (Fig. 1). This region has recorded 125.2% increase in livestock population within a span of 56 years (1956-2012). During this period population of cattle and sheep increased by 57.7 and 44.8%, respectively while

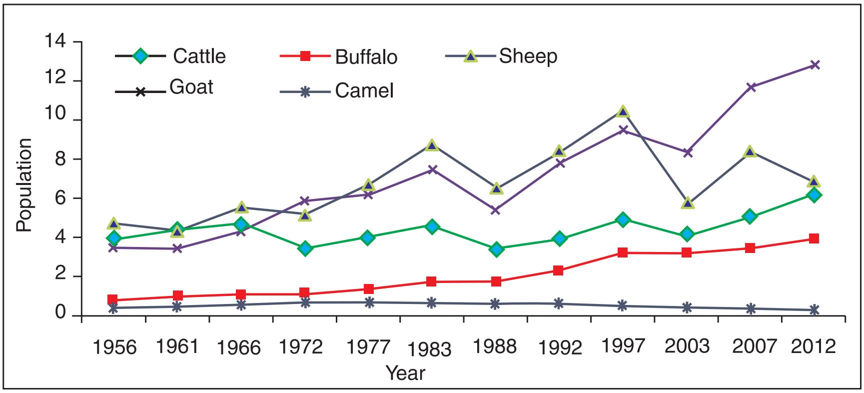


**Fig. 1** Changes in livestock population in arid Rajasthan over the years

very high increase was registered in the number of goat (266.4%) and buffalo (412.5%). Buffalo population has increased mainly due to increase in irrigated area and preference towards stall feeding. Share of buffalo in livestock population is only 11.8%, but it contributes 45.2% of total milk production in arid region. Arid Gujarat has 1.13 m livestock population, and the share of sheep, goat, cattle and buffalo is 31.6, 26.6, 25.3 and 8.5%, respectively.

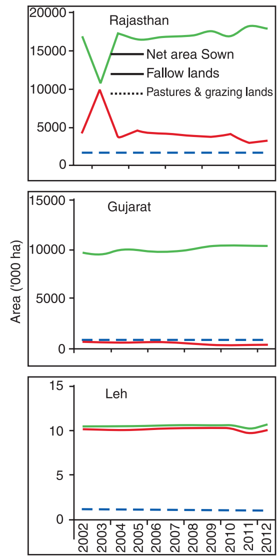


**Fig. 2** Land use changes

**Land:** Arable land per person has decreased ~2% per annum in India during 1970-2009. Net sown area in predominantly hot arid states of Rajasthan and Gujarat has shown increasing trend but mainly at the cost of fallow lands (Fig. 2). Increasing demand of land for many non-farm sector activities like mining, tourism, oil exploration and other industrial/infrastructure developments is likely to significantly reduce the availability of arable land in the years to come.

Land degradation is a major problem of arid regions (Fig. 3). Maximum land degradation in Rajasthan is in arid districts of Jaisalmer (2.77 m ha), followed by Bikaner (2.12 m ha), Barmer (1.92 m ha), Churu (1.38 m ha) and Jodhpur (1.24 m ha). Wind erosion is a major contributor to land degradation (11.42 m ha) in Rajasthan. In Gujarat, saline soils account for 1.56 m ha; of which 0.58 m ha is in arid Kachchh district alone. Rajasthan has the maximum degraded area (21.8%) of the country, followed by Jammu and Kashmir (12.8%),

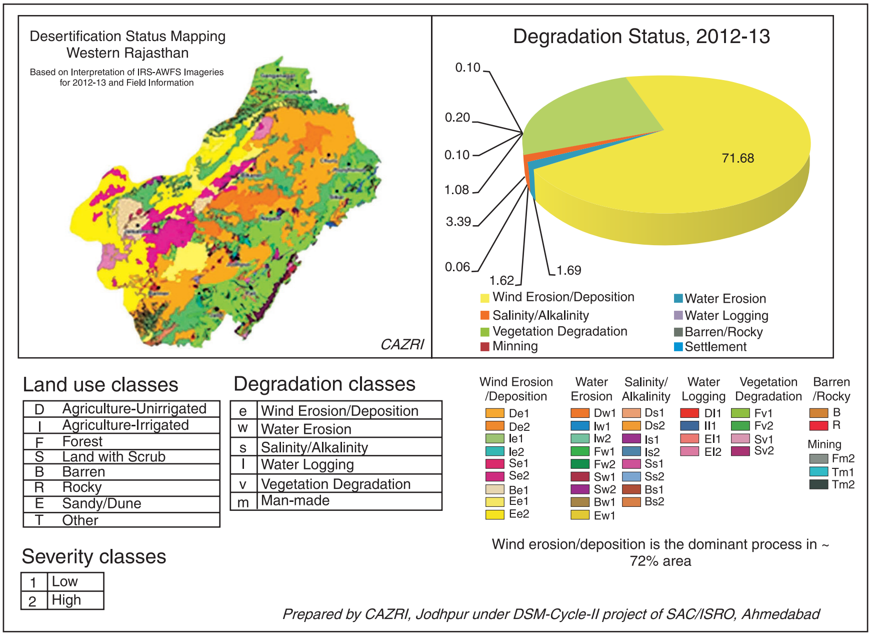


**Fig. 3** Desertification status in arid Rajasthan

Maharashtra (12.7%) and Gujarat (12.7%). Soil erosion can be reduced through plantation of trees, shrubs, grasses; shelterbelts and windbreaks; rangeland management and pasture development.

**Water:** Hot arid zone relies heavily on groundwater for irrigation due to limited surface water resources. High reliance on groundwater extraction results in its over utilization (Fig. 4), resulting in rapid decline in groundwater level. For example, out of 249 blocks in Rajasthan, only 40 blocks are in the 'safe category' in this respect and most of the others are in the 'dark zone'.

Indira Gandhi Nahar Pariyojana (IGNP), with a targeted canal command area (CCA) of 1.537 m ha was initiated in 1960. However, injudicious use of canal water led to problems of water logging and secondary salinization. Central Ground Water Board estimated that 2.6% of CCA in Stage-I was water logged, 4.18% was in critical stage and 39.0% (0.2 m ha) was potentially sensitive area for water logging in 1992. Subsequent efforts like afforestation, development of groundwater for conjunctive use and rationalization of canal water supply reduced total water logged area from 13 thousand ha in 2000-01 to 2.2 thousand ha by 2008 (Command Area Development and Water Utilization Department, IGNP, 2009). However, potentially sensitive area to water logging is still about 0.19 m ha.

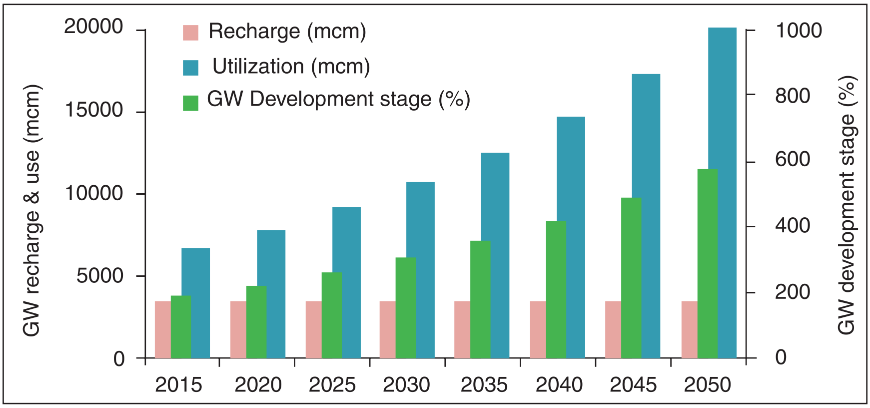


**Fig. 4** Projected groundwater (GW) recharge and utilization in arid Rajasthan

**Climate change:** India Meteorological Department (IMD) has estimated that surface air temperature in most parts of India has already increased by about half a degree during the second half of the 20th Century. Using four Representative Concentration Pathways (RCPs) and 18 General Circulation Models (GCMs) under the Coupled Model Inter-comparison Project-5, Chaturvedi *et al.* (2012) reported that under the business-as-usual scenario, mean warming in India is likely to be in the range 1.7 to 2°C by 2030s and 3.3 to 4.8°C by 2080s relative to pre-industrial time (1880). All-India precipitation under the business-as-usual scenario was projected to increase from 4 to 5% by 2030s and from 6 to 14% towards the end of the century (2080s) compared to the 1961–1990 baseline. However, they cautioned that the precipitation projections were relatively less reliable than temperature projections. The models showed a consistent increase in number of extreme rain fall days over the long term (2060s and beyond) period.

Direct effects of climate change on agriculture are likely to be through changes in temperature, precipitation, length of growing season, and timing of extreme or critical threshold events relative to crop development, as well as through changes in atmospheric $CO_2$ concentration. Indirect effects may include potentially detrimental shifts through increased incidence of disease, pests and weeds. Climate change may become a major challenge for arid agriculture in future, particularly in the hot arid regions. It is estimated that in the tropics where some crops are near their maximum temperature tolerance and where dryland agriculture predominates, yields are likely to decline. Studies indicate that rise in temperature will adversely affect the potential as well as water limited yields of crops across the hot arid regions. Climate change poses formidable challenges to the animal husbandry sector as well. Heat stress in dairy animals is likely to impact their productive and reproductive performance. In cold arid regions, increase in length of growing season may be beneficial, but adjustments in cropping/farming systems might be required to adjust with the climate change scenario.

**Depleting non-renewable energy resources:** Like other areas, use of tractors, diesel/electricity operated pumps, threshers and other farm machinery has increased several folds in arid regions also during last 5-6 decades. The cost of cultivation increases with increase in price of diesel/ electricity. Secondly, the fossil fuel based energy resources are depleting fast and are not going to stay for long. Arid regions, particularly the hot arid areas, are endowed with long and intense sunshine hours along with regular wind speed. This provides ample scope for utilization of renewable energy resources. Research efforts, therefore need to focus on development of energy efficient devices for effective utilization of these natural resources. CAZRI has developed several solar energy based devices. Besides, other renewable energy resources like wind and biogas have bright future and require focussed attention. Light weight tools for manual operation need to be developed to reduce human drudgery. Combo implements and tools with renewable energy system need to be explored for practicality and wider adoption.

**Supply chains:** The world trade and IPR regimes are important issues likely to affect the agricultural scenario of the country in next 3-4 decades. The arid zone grows export oriented crops like cluster bean (*guar*), cumin, *isabgol*, etc. The growers are, however, at receiving ends due to lack of policies and guidelines in marketing and global trade. Similarly marketing of fruits and vegetables (particularly of cold regions) requires proper marketing strategies. Developing and transferring technology alone will not close yield gaps and reduce wastage and post-harvest losses. It requires an enabling and conducive investment environment. Farmers are likely to adopt technologies only if there are incentives. This calls for adequate input and output markets, better infrastructure, as well as finance and risk management tools. The same applies to the reduction of wastage and post-harvest losses, which require better-functioning supply chains. ❑

# Operating Environment

INDIA has about 32 m ha area under hot arid zone spread in seven states, in addition to 7m ha area under cold arid zone (Rai and Bawa, 2001). Arid and semiarid regions of India are shown in Fig 5.

The focal operating environment of CAZRI is the hot and cold arid regions of the country. Most of the hot arid zone is part of the Thar Desert, a mid-latitude desert spread in India and Pakistan. About 90% of the Indian hot arid zone lies in states of Rajasthan, Gujarat, Punjab and Haryana while some pockets lies in Andhra Pradesh, Karnataka and Maharashtra also (Fig. 6).

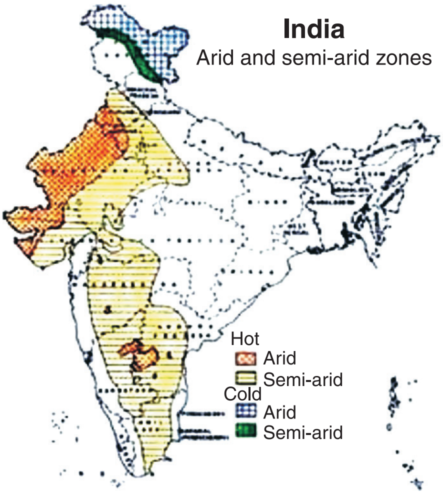


**Fig. 5** Arid and semi-arid regions in India

Hot arid regions are characterized by scanty and erratic rainfall, high temperatures and strong wind causing high evapo-transpiration,

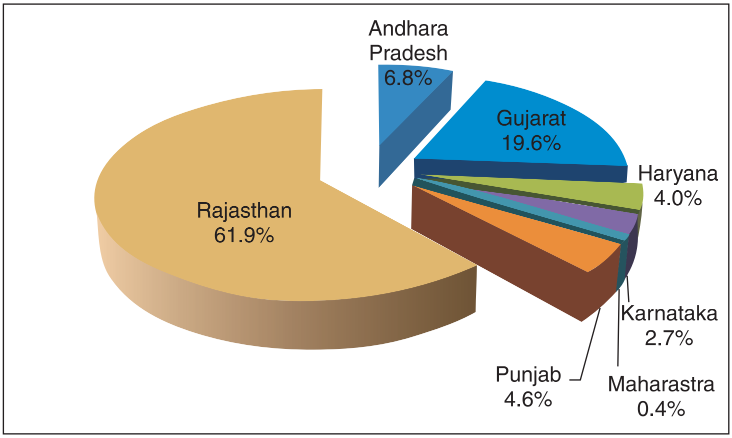


**Fig. 6** State-wise distribution of hot arid zone in India

extremes of aridity and low biomass producing conditions, sandy terrain, which is low in organic carbon and water holding capacity.

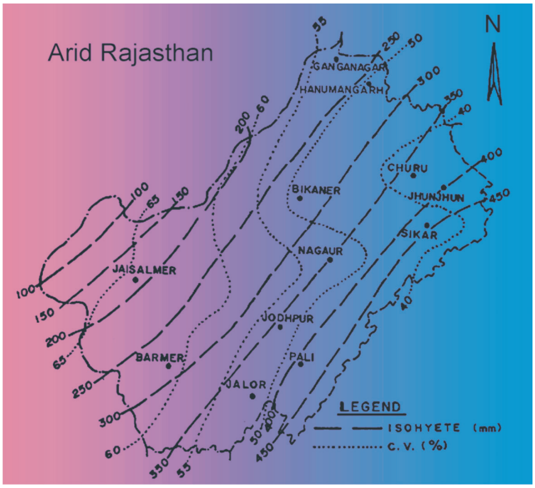


**Fig. 7** Annual rainfall distribution and its CV in arid Rajasthan

Average annual rainfall in hot arid region ranges from 100 to over 450 mm. Over 85% of this rainfall is received during the monsoon season (June-September). However, its inter-annual and seasonal distribution is highly erratic. The coefficient of variation (CV) of annual rainfall (Fig. 7) ranges from 36% in the eastern part to 65% in the western part of Rajasthan (Rao, 2009). Distribution of rainfall during the crop growing season plays important role rather than annual rainfall total. The unreliability of precipitation is more significant than the totals. For example, Churu district faced moderate to severe drought in one out of five years, while there were 2 to 3 drought years out of five years in Barmer and Jaisalmer districts. Based on district wise annual rainfall data of 1901-2002, Rathore (2004) estimated that there were droughts of various intensities during almost half of the years in arid districts of Rajasthan. High temperature during *kharif* season along with high wind speed and low relative humidity exacerbate the adverse effects of low and erratic rainfall.

Soils are mostly light textured with low organic matter content and water holding capacity and are prone to soil crust formation after light rains. Soil crust hinders the emergence of seedlings which ultimately affect the plant population. Crusting of soil surface reduces infiltration rate of rain water and increases run off. Presence of hard layers (pans) in soil is another problem that restricts soil depth and rooting zone.

Rajasthan has been divided into ten agro-climatic zones and five of these zones are in arid region. Out of seven agro-climatic zones of Gujarat, the North-West Zone falls under arid zone which comprises Kachchh district and parts of Banaskantha, Surendranagar, Mehsana, Ahmedabad and Rajkot districts. This zone accounts for 23.3% of total geographical area of the state. Pearl millet, sorghum, wheat, arid

**Cold arid zone**

About 7 million ha area of India is in cold arid zone comprising mainly of Leh and Kargil districts of Jammu and Kashmir, and Lahaul and Spiti along with some parts of Chamba and Kinnaur districts of Himachal Pradesh.

In the cold arid region, the high-altitude (2500 to 7500 m) and harsh natural environment of Ladakh is characterized by extreme temperatures (-30°C to 30°C), high radiation, strong winds, low precipitation (<100 mm $y^{-1}$), low humidity; extensive barren landscape, rugged topography, steep and vertical glaciated slopes, minimal forest cover and few pasture lands at high elevations (Kumar *et al.*, 2009). Agro-climatic conditions vary considerably with altitude. Only *kharif* season crops can be taken as the winter season is very harsh. Sharma (2000) reported that depending upon altitude, the growing season varies from two (above 4000 m) to five months (below 3000 m). Agriculture depends mainly on glacier fed rivers.

In Leh and Kargil districts of cold arid region, cultivated lands constituted 32.2% of the total reporting area in 2010-11, which includes 30.5% net sown area, 1.2% current fallow and 0.6% other fallow land. Forest occupied 0.1% area, land put to non-agricultural uses 6.3%, barren and uncultivable land 46.0%, pasture 1.7%, miscellaneous tree crops and groves 2.3% and cultivable waste 11.3%. Contrary to it, in Lahaul & Spiti district of Himachal Pradesh cultivated lands constituted only 0.4% of the total reporting area with no fallow lands. Forests occupied 14.9% area, and 14.9% area was under non-agricultural uses. Barren and un-cultivable land was 45.6% and 24.2% land was under permanent pastures and other grazing lands.

Wheat, barley, pea, beans, maize and millets like ragi are important crops of cold arid region. These are taken mostly under irrigated condition. Apricot, apple and walnut are major horticultural crops while poplars and willows have been popularised especially in Lahaul and Spiti and Laddakh. Cattle, Yak, sheep and goat find important place in farming systems. This region is also rich in medicinal flora.

legumes, groundnut, sesame, caster, cotton and mustard are important crops of this zone.

As per land use statistics of 2010-11, net sown area was 56.8%, current fallow 4.7% and other fallow land 5.8% of arid zone in Rajasthan. Among other uses, forestland occupied 3.0%, pasture 4.0%, land put to non-agricultural uses 5.0% and barren & uncultivable land 4.8%. In arid Rajasthan, net irrigated area is 13% of its total geographical area, while the corresponding figures for Gujarat, Punjab, Haryana, Andhra Pradesh and Karnataka are 17, 88, 76, 8.5 and 17%, respectively.

Pearl millet is the most important food crop of hot arid region and about 25% of total acreage of this crop in the country is in arid regions. Clusterbean, moth bean, cowpea, and horse gram are predominantly grown in the arid zone. The area of clusterbean in Rajasthan hovers around 2.5 m ha while the productivity is around 250 kg $ha^{-1}$. Moth bean is cultivated in about 1.4 m ha with productivity of less than

200 kg ha$^{-1}$, while cowpea is cultivated in 0.12 m ha with productivity of over 300 kg ha$^{-1}$. Almost 80% acreage of clusterbean and 90% of moth bean lies in arid districts. Sesame is an important rainfed oilseed crop of arid region and Rajasthan has 18.2% share in area and 14.1% in production. It is cultivated in about 19,000 ha in arid Gujarat. Groundnut and castor are grown in 80,000 and 40,000 ha area of arid Gujarat. Seed spices like coriander, cumin, *isabgol*, fennel and fenugreek are mainly grown under irrigated condition. Important horticultural crops of hot arid region are *ber*, pomegranate, *aonla*, *bael*, *gonda* and date palm. Many medicinal plants (*Aloe*, *sonamukhi*, etc.) are also grown in hot arid regions.

Despite the fact that agricultural productivity in hot arid region is low due to harsh agro-climatic conditions, the situation has improved in recent years. The Compounded Annual Growth Rate (CAGR) of food grain productivity during the 1999-2000 to 2010-11 was 3.2% in Rajasthan and 4.9% in Gujarat, well above the national average of 1.6%. Despite that, average food grain productivity during the 4 years of the 11$^{th}$ five year plan (2007-08 to 2010-11) in Rajasthan was only 1154 kg ha$^{-1}$ which was far below the national average of 1872 kg ha$^{-1}$. Food grain productivity in Gujarat (1708 kg ha$^{-1}$) was relatively better.

Broadly, the hot arid region has surplus production of cereals and pulses, but production of oilseeds, fruits and vegetables still lag far behind the current demand.

Improvement in agro-technologies coupled with infrastructural developments has shown better achievements in terms of rural livelihood security. IGNP has brought large parts of the driest and the dune-covered western-most districts of Rajasthan under irrigated agriculture with many new and high value crops. However, irrigation in desert through IGNP has created secondary problems like water-logging, soil salinity, etc. which may accentuate further, if not managed properly.

Area under fruits and vegetables is very less in the hot arid region. Gujarat and Rajasthan have only 6.1 and 6.7% share in country's area under fruits and vegetables, respectively. About 57.6% of India's area under aromatic plants is in Rajasthan, but contribution in production is only 25.9%. Rajasthan has 19.9% share in country's area under spices with only 10.9% contribution in production, while Gujarat contributes 10% in production with 10.8% share in area. The horticulture sector has to play a major role in diversification of agriculture.

Livestock farming is a major economic activity contributing substantially (up to two third of the total earning) to the farmers' income in the arid areas. Although per unit productivity of livestock is lower

**Table 1** Important live stock breeds of the Indian arid zone

| Region | Cattle | Buffalo | Sheep | Goat | Camel | Horse |
|---|---|---|---|---|---|---|
| Hot Arid Zone | Tharparkar, Kankrej, Nagori, Rathi | Graded-Murrah, Surti, Mehsana | Marwari, Magra, Nali, Jaisalmeri, Pugal, Chokla, Kheri, Patanwadi | Marwari (Barmeri), Parbatsari, Jhakarana, Kachchhi | Bikaneri, Jaisalmeri, Kachchhi | Marwari (Malani), Kathiawadi |
| Cold Arid Zone | Yak (*Bos grunniens*), Yakow: d*zo* (male) and d*zomo* (female) | | Malluk, Merino-Malluk hybrids, Changthangi (local name Changluk), Purik | Chedu, Chang-thangi (reared for *Pashmina* wool) | Asiatic double-humped camel | Zanskari, Sipti |

than in the irrigated areas, there is inherent potential for drought/heat resistance in the desert livestock breeds (Table 1).

More than 51% of the livestock of Rajasthan is concentrated in the arid areas, but their productivity is low primarily due to scarcity of good quality fodder and critical nutrients, which are required for maintenance of normal physiological functions, production and reproduction of the animals. Most of the livestock population in the state is range managed. The range grasses and crop residues are very low in essential nutrients including fermentable energy, protein, minerals and carotene. The problem of mineral deficiency is further aggravated due to high calcium and very low phosphorus content of the crop residues. Calcium-phosphorus imbalance adversely affects the availability of calcium and phosphorus. Fodder scarcity is another problem. In normal rainfall years, dry fodder and green forage availability is 82.1 and 31.6% of demand, respectively. This situation is further aggravated during drought years.

Large yield gaps exist between the experimental yields and those obtained at farm level. Concerted efforts are required to bridge this gap and the potential of the region needs to be carefully exploited through crop-livestock-horticulture-silvi-pasture based farming systems for a sustainable future.

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# New Opportunities

EDUCATED, informed, tech-savvy innovative farmers of 21$^{st}$ century will probably provide the greatest opportunity to bridge the yield gaps, reduce the technology adoption lag and sustainable development of arid agriculture.

A lots of information is being collected/generated by various departments/organisations including status of natural resources like surface and groundwater, soil fertility, land utilization, education and human resource development, socio-economic as well as food and nutritional status of rural masses, etc. Recent developments in information technology (IT) and computer application have provided excellent opportunities for creation and management of databases of information collected by different agencies, their analysis and integration for development of appropriate decision support systems (DSSs). Expert systems using such DSSs, farm level soil data base, current crop condition from high resolution satellite imageries, current and forecast weather, shall further provide opportunities for real time farm-level agro-advisories in the form of text, voice, image and/or video message(s). Advances in remote sensing, spatio-temporal data management systems and high computational power is likely to open new vistas for almost real time assessment, monitoring and forecasting of the state of natural resources for their efficient management and prompt corrective measures, if required.

Climate change will have diverse implications in different agro ecosystems through impacts on agriculture, water resources, forestry & biodiversity, energy and infrastructure. National Action Plan on Climate Change (NAPCC) prepared by Govt. of India in 2008 set eight missions to respond to climate change namely, National Missions on Solar Energy, Enhanced Energy Efficiency, Sustainable Habitats, Water, Sustaining the Himalayan Ecosystem, Greening India, Sustainable Agriculture and Strategic Knowledge for Climate Change. CAZRI in collaboration with state governments, other research institutes in hot and cold arid regions, will have an opportunity to contribute to all the eight missions of NAPCC. Elevated temperatures in hot arid region are most likely to have adverse impact on crop and livestock productivity that need to be addressed through an array of selection, breeding and management strategies. In cold arid zone, climate change may provide an opportunity to capitalize on increased length of favourable growing season through appropriate mix of farming system components.

Water (rain, surface and ground water) is and will remain the most limiting factor in arid zone agriculture. The future R&D strategies need to be focussed on maximising water productivity rather than land productivity. Judicious integration of recent and future developments in water absorbing polymers, efficient water conveyance and delivery systems, efficient greenhouse designs, cost effective soil moisture measurement sensors, etc. with conventional wisdom will give an opportunity to increase water productivity several fold.

The germplasm of both plant and animal origin is available that is well adapted to extreme conditions of arid zone like high and low temperature stress, water, nutrient and salinity/alkalinity stresses. There is need to have a systematic approach to conserve, augment, sustainably use and benefit from these resources. Advances in biotechnology and genetic engineering will provide great opportunity to use such novel genetic material for development of different type of varieties/breeds suitable for different agro-climatic and management conditions.

Demand for organic products and organic food is increasing both in domestic and international markets. Demand for herbal and medicinal plant products is also increasing globally. The arid regions are hot spots of biodiversity with a variety of medicinal and aromatic plants, underutilized vegetable and fruit crops. Identification, characterization and development of high yielding/ high quality genotypes of such plants, trees and shrubs for their integration in farming systems suitable for agro-climatic conditions and farm resources will provide opportunity to diversify the farming systems. The hot arid region is endowed with many high value crops like cumin, *isabgol*, clusterbean, etc. that can earn foreign exchange, if grown organically. Complete package of practices for organic farming of such crops need to be developed to cash in on this opportunity.

Global fruit and vegetable production has experienced a remarkable increase, growing at annual rates of around 3% and 5%, respectively, in the past two decades. This implies that horticultural crop production generates high economic returns per unit of land, offering promising incomes, especially for the smallholders. In addition, being labour intensive, the horticulture sector contributes to poverty reduction by providing employment opportunities. There is ample scope of increasing both area and productivity of vegetables and fruits in the hot as well as cold arid region as the current production level is low and the demand for and returns from such crops are high. Protected agriculture, especially in cold arid regions too has greater scope for high value vegetables, fruits and floriculture.

Traditionally, the livestock rearing has relied more on numbers rather than productivity per head. Increasing demand for and price of meat, milk and milk products will be boon for this sector. However, extensive grazing practice will have to be replaced by semi-extensive grazing and stall feeding practices due to shrinking grazing resources. Future breeding, feeding, shelter and heath care strategies have to be evolved around such management system for increased productivity per head. Consumption of poultry meat is increasing. Integration of poultry production in farming systems has ample scope.

Significant losses occur at the time of harvest of the crops and during post-harvest processing and storage. For field crops, drying, threshing and milling can cause huge losses, while poor handling, packaging and transport of perishable fruits and vegetables can cause substantial wastage. There can also be losses during food processing. Such losses also result in wastage of human labour, land, water, fertilizer and other inputs, as well as fuel for transportation, processing and cold storage. Development or adaptation of state of the art machinery and processing facilities to minimize such losses should get high priority. Demand for pre-processed and packaged food is increasing. Processing and value addition near the site of production (farm, village or cluster of villages) will reduce the post-harvest losses and provide higher income to farmers and employment opportunities to rural youth in village(s) itself.

Viable technologies for efficient conversion of solar and wind energy are emerging that need to be exploited fully to reduce dependence on petroleum, fuel wood and cow dung based energy. Harnessing of renewable energy (solar/wind) and its use at affordable price for different farm and domestic operations will be environmentally friendly and much needed organic matter (FYM) will be available for improving soil productivity. Gujarat and Rajasthan are leading states in solar power generation. Considering the need of cleaner energy resources, abundant availability of solar radiation in arid region and declining costs of solar PV panels, arid regions have tremendous potential for solar power generation. Solar and wind power generation also offers opportunity of land and income diversification. Initially, degraded and low productivity lands may be put under solar/wind farming. Water harvested from solar panels can be used for growing of food and fodder crops in strips or biodiversity conservation and enrichment.

Carbon trading may be a new area from which arid region may benefit. Plantation for sanddune stabilization and on degraded lands, shelterbelt plantation, agroforestry, etc., will not only green the desert but also earn the carbon credit. ❑

# Goals and Targets

THE following strategic frame work has been formulated for addressing the major issues by 2050.

| Goal | Approach | Priority | | |
|---|---|---|---|---|
| | | 2015-30 | 2031-40 | 2041-50 |
| Natural Resources Monitoring | Integrated assessment of natural resources (i.e. soil, water, vegetation) and development of DSS for their monitoring and management at cadastral level | H | H | M |
| | Quantitative analysis of local and regional patterns of land use change and its impact on the natural resources | M | M | M |
| | Land degradation vis-à-vis crop productivity and socio-economic conditions | H | H | H |
| | Plant diversity distribution, modelling, and informatics management for ecosystem stability at local and regional level | H | M | L |
| | Monitoring of sand dunes (i.e. changes in dune drifting, morphology, vegetation, hydrology, physical, chemical and biological characteristics of soils) and desertification control at cadastral level | H | H | M |
| | Impact assessment of major canal projects (IGNP and Narmada), industrial effluents and petro-chemical industries on natural resources | M | M | L |
| | Soil fertility assessment, carbon sequestration and C- and N-pool budgeting at ecosystem and agro-ecosystem level | M | M | M |
| | Soil bio-diversity and its utilization in agricultural production systems | H | M | L |
| | Weather monitoring for early warning of extreme weather events like drought, flood, heat and cold wave; and weather-based agro-advisories | M | M | M |
| Integrated Farming Systems and Precision Farming | Diversified farming system having multiple components of livestock, crop, horticultural, medicinal, aromatic and fodder species so as to withstand biotic and abiotic stresses | H | M | M |
| | Suitable farming systems, including area specific crops, for maximising water productivity of rain and irrigation waters | H | M | M |
| | Protected agriculture of high value crops for quality products | M | H | M |
| | Integrated watershed management,in-situ moisture conservation, rain water harvesting, evaporation reduction for conjunctive use and groundwater recharge | H | M | M |
| | Rehabilitation technologies for lands degraded due to anthropogenic actions viz., mining, water logging, salinization, overgrazing, crude oil prospecting and processing, thermal power plants, etc. | M | H | M |
| | Area specific shelterbelts and windbreaks to minimize soil erosion, create favourable microclimate for crop growth leading to enhanced productivity | M | H | M |
| | Technology development to produce and multiply quality seeds/ planting material | H | H | M |

| | | | | |
|---|---|---|---|---|
| Biodiversity Conservation and Genetic Enhancement | Exploration, collection, introduction, evaluation, conservation and maintenance of germplasm of crops, pasture grasses, shrubs, horticultural and agroforestry trees of arid regions and development of promising varieties for diverse situations | H | H | H |
| | Selection, characterization and development of drought, salinity and high temperature tolerant/resistant genotypes | H | H | M |
| | Evaluation of crops for resistance to diseases and pests and development of elite breeding materials | H | H | M |
| | Tapping of underutilized and un-explored arid zone plants for products of economic importance like tans and dyes, gums, resins, oleo-gum resins, drugs, insecticides, biofuel, feed, etc. | H | M | M |
| Molecular and Biochemical Aspects for Plant Improvement | Biochemical and molecular assessment of genotypes for abiotic stress tolerance and their use in plant improvement | H | H | M |
| | Development of molecular markers and their use in plant breeding | H | M | M |
| | Bio-prospecting for genes and molecules | H | M | M |
| | Development of transgenics for biotic and abiotic stress tolerance | H | M | M |
| | Functional genomics and phenomics | H | M | M |
| Sustainable Livestock Production Systems | Comparative studies on adaptability, health, reproduction and production systems of cattle, buffalo, sheep and goat | H | M | L |
| | Research on efficient utilization of native, unconventional and un-explored feed and fodder resources | M | M | M |
| | Improvement of rangelands/grasslands in a participatory mode | H | M | M |
| | Development of region-specific mineral mixture | H | M | M |
| | Development of value added animal based products for poverty alleviation | H | M | M |
| Nano-technology for Enhancing Crop Productivity | Nutritional management of arid zone crops through nano particles | H | H | H |
| | Development of tolerance against abiotic and biotic stresses in important plants of arid zone | M | H | H |
| Integrated Pest Management (IPM) | Isolation, selection, multiplication and bio-formulations of bio-control agents, bio-pesticides and biomolecules for management of diseases, nematodes, insect and vertebrate pests of crops, trees and shrubs | H | H | M |
| | Dynamics of insects and pests and their natural enemies in farming systems | H | H | M |
| | Molecular mechanism of pest/ disease resistance and development of early diagnostic molecular techniques | H | M | M |
| | Impact of climate change and land use pattern on insect pests, rodents, diseases and weeds dynamics | H | H | H |
| | Development of IPM schedules in context to climate change | H | H | H |
| | Non-lethal approaches and their integration with chemicals for integrated rodent pest management | M | H | H |
| Development of Renewable Energy and Solar Devices for Energy Security | Evaluation of new emerging technologies and development of solar thermal, PV and hybrid systems with solar and wind energy for a variety of end uses | H | M | L |
| | Design and development of energy storage systems for extended use | L | M | H |
| | PV-based micro-irrigation systems for different scale of application and energy-mass modelling for optimized utilization | H | M | L |
| | Nanotechnology for solar systems | L | M | H |
| | Technology development for integration of solar as well as wind farming | H | H | M |
| | Establishment of arid zone renewable energy centre (AZREC) | H | M | L |

| | | | | |
|---|---|---|---|---|
| Farm Mechanization | Development of efficient farm machinery and implements | H | M | L |
| | Ergonomically designed combo tools with alternative materials | L | M | H |
| | Renewable energy driven implements and tools | M | H | L |
| | Biosensors and low cost instruments for resource monitoring | L | M | H |
| Process Engineering and Value Addition | Development of processing equipments for functional and nutritional foods, medicinal plants | H | M | L |
| | Development of value added products from arid crops/plants like mothbean, clusterbean, pearl millet, *kair*, *khejri, kumut*, date palm,, *tumba*, medicinal and aromatic plants for niche markets | H | H | M |
| | Technology development for packaging, processing and transportation of fruits, vegetables and spices | L | M | H |
| | Technology for improving shelf life of durable and perishables | L | M | H |
| Impact Assessment, Evaluation of Sustainable Farm Business Modules and Marketing | Socio-technical implications of technology dissemination | H | H | L |
| | Market linkages, intelligence and externalities in entrepreneurship development | H | M | M |
| | Accumulation of gender disaggregated data of existing agro-technologies for women entrepreneurship | M | H | H |
| Participatory Technology Evaluation, Dissemination and Capacity Building | Technology assessment, refinement and transfer through on-farm projects | H | H | H |
| | Development of customised training modules, approaches and contents for capacity building of farmers, farm women, rural youth and other stakeholders | H | H | L |
| | Improving research efficiency through regular outreach approaches/ programmes | H | H | H |
| | Organization of specialized trainings for extension workers and stakeholders | M | M | H |
| | Prioritization of research initiatives for constraint analysis and socio-cultural dominance in arid areas | H | M | L |
| | Integrated rural resource management through satellite links of village resource centre and convergence into flagship and welfare programmes | L | H | H |
| Socio-economics of Mainstreaming Climate Resilient Agriculture in Arid Regions | Micro-level sensitivity of arid agriculture to climatic variability, mitigation options and adoption | M | H | L |
| | Economics of adaptation to climate change and policy support options for up scaling | M | H | H |
| | Empowering women and vulnerable socials for adaptation to climate change | H | H | L |

(H: High, M: Medium, L: Low)

# Way Forward

At the time of independence, mostly rainfed subsistence farming was common in the hot arid region. There have been substantial changes in agricultural practices since then due to increased irrigation facilities, availability of improved seeds, fertilizers, pesticides and management practices. CAZRI has witnessed such changes and has contributed substantially in technology development/improvement. It would use its vast experience coupled with advances in agriculture and allied fields around the world to address the emerging challenges for sustainable agriculture. CAZRI has envisioned *'a greener, climate resilient arid land with well managed and sustainable agriculture that provides improved livelihood options and conserves scarce natural resources'*.

In view of the inherent problems of arid zones and likely problems posed by global climate change, sustainable development of these regions is a challenging task. Despite that, the region has strengths in terms of rich biodiversity adapted to harsh conditions, availability of vast stretches of land resources and renewable energy resources. CAZRI is committed to convert these weaknesses and strengths of arid zone into opportunities for enhancing the overall productivity of land and animal wealth so as to meet not only the regional and national requirements but also to produce surplus for exports.

Many areas of the arid zone have started facing problems of water scarcity and natural resource degradation due to indiscriminate use of the scarce natural resources. Another major threat facing the arid areas is climate change, and more specifically the problems associated with rising temperature and aberrant rainfall. The institute will focus on increasing water and land use efficiency. Efforts will be made to increase the productivity of livestock-based farming system, agroforestry, diversified agriculture, conservation agriculture and range management that are the backbones of agriculture in this region. Efforts will be made to better understand the drivers of change (both natural and human-induced), the rates of current atmospheric and land surface processes and their impact on resource availability and distribution. CAZRI will also focus on understanding and mitigation of the vulnerability of agriculture and people to droughts, desertification and climate change.

Not only the extreme vulnerability of arid production systems need to be addressed, but their potentials also need to be carefully exploited through crop-livestock-horticulture based farming systems for a sustainable future. Area under irrigation through large canal projects (IGNP and Narmada canal) and tube wells is increasing. Despite that the dryland production system will predominate. However, the irrigated farming systems can produce much higher than the rainfed systems, and can support higher bovine population that has better production efficiency in economic terms than the huge number of ovines with smaller economic returns on the vast rangelands that are presently highly degraded. Unless a technology-mediated change, backed up by sound policy instruments, is effected in the crucial components of these production systems, there is less scope for improving the agricultural economy of the region as a whole.

One of the major requirements is to genetically improve the adaptation, thermal and drought stress tolerance and other necessary traits of the plants to provide higher grain and/or fodder yields. Development of short-duration and resistant cultivars through selection and bio-technological mediation will reduce the risk of uncertain weather. The priority crop species for CAZRI are pearl millet, moth bean and cluster bean, where CAZRI has developed sufficient specialization and these may be future crops as health and industrial foods. Likewise, among perennials, range grasses, and trees and shrubs like, *Prosopis cineraria*, *Acacia* spp., *Capparis decidua,* etc., too will receive focused attention, along with a few fruit crops like, ber, aonla, pomegranate, aloe, date palm, etc.

CAZRI has developed a number of improved varieties and production technologies of horticultural crops like *ber*, pomegranate, *aonla*, etc., that are mostly sold in the market as raw products. Besides integrating these fruit crops in farming systems mode for sustainability, our concerted focus on R&D on adding value to these fruits will vastly improve their market potentials and help in rural employment generation and nutritional security of the people. Plant biodiversity of the arid region has to be maintained and harnessed scientifically for improving the livelihood of the rural people. Plants like *Commiphora wightii* (Guggal) are now on the verge of extinction due to over-exploitation, while others like *Aloe vera*, *Citrullus colocynths*, *Citrullus lanatus*, *Cucumis callosus*, *Cucumis melo*, *Salvadora oleoides, Acacia senegal*, etc., have received little attention for medicinal, industrial and food values. Technologies for deriving benefits from these and other local plant materials shall be strengthened. Augmentation of post-harvest technology for the arid zone produces and their value addition will receive utmost attention to minimize losses, generate employment and increase profitability. Avenues for market chains are to be explored and suggested for higher economic gains to producers and ultimate consumers.

Arid areas are well-endowed with solar and wind energy, and there is vast scope for their systematic harnessing for agricultural and domestic uses. CAZRI has developed some low-cost solar appliances for cooking food and feed, heating water, making candles, drying agricultural produces, etc. Concerted efforts will be made to derive the benefits of photovoltaics, chemical cells, etc., for effective utilization of the clean energy sources at affordable cost by the rural masses. Solar farming with emphasis on effective utilization of inter spaces between solar panels will also be a focused area of attention of CAZRI in future. Design and development of efficient and low-cost tools and implements for various agricultural operations will be continued to reduce drudgery in field operations.

Utilizing the gains in IT sector, modalities for exchange and sharing of information, knowledge, expertise, experiences and technologies will be developed to ensure that scientists and stakeholders are able to find viable solutions together. Technology transfer, human resource development and capacity building will be strengthened for faster diffusion of technologies to stakeholders. The technology integration and packaging system through participatory on-farm trials and refinements will need highly trained and motivated extension workers.

CAZRI has so far mainly concentrated its efforts in hot arid region of North-West India. However, in recent years the institute has established networks to cover most of the hot and cold arid regions of the country. The R&D efforts would be strengthened on priority through these initiatives.

CAZRI, being a pioneer research institute, envisions to serve as a nodal Institution for developing, synthesizing and collating the database generated by other R&D Institutes of the region in evolving holistic development plans for the region. For the purpose effective networking, sharing of information and resources through well-structured linkages will be strengthened to invoke inter-institutional and regional collaboration which would provide synergistic benefits for arid zone dwellers of the country and elsewhere.

Dedicated, motivated and well equipped manpower can only achieve such goals. It will be vital that all the sanctioned posts are filled and the scientists get proper exposure and training in emerging fields. The scientists and technical staff will need training at national/international level in the field of nanotechnology for its use in solar cells, saline/waste water treatment, packaging, agricultural inputs, etc. Suitable training will be required for precision farming, protected agriculture, biotic and abiotic stress management, embryo transfer technology for improvement of local breeds, market intelligence, etc.

State of the art facilities are prerequisite to excel in science. Establishment of a centre of excellence on desert studies, centre for post-harvest technology of arid produce, facility for application of space technology for arid agriculture and facility for embryo transfer technology, phytotron facility will be required in addition to modernization of laboratories with state of the art equipment like DNA sequences, ICPMS, SCM, XRD, etc.

CAZRI has well established linkages with national and international institutes, SAUs and departments. The linkages will be strengthened with centre and state Departments of agriculture, horticulture, forest, animal husbandry and extension; space application centers; ground water boards, etc. At national level linkages will be strengthened with various ministries and departments like ministry of environment, forestry and climate change; ministry of earth sciences, ISRO, CSIR, ICMR, DST, DBT. Cooperation with international organizations and research institutes like FAO, UNESCO, UNEP, UNCCD, Biodiversity international, ICRISAT, ICARDA, ICRAF and other CGIAR institutes will be promoted.

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# NOTES

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