CAZRI Perspective Plan

VISION-2025

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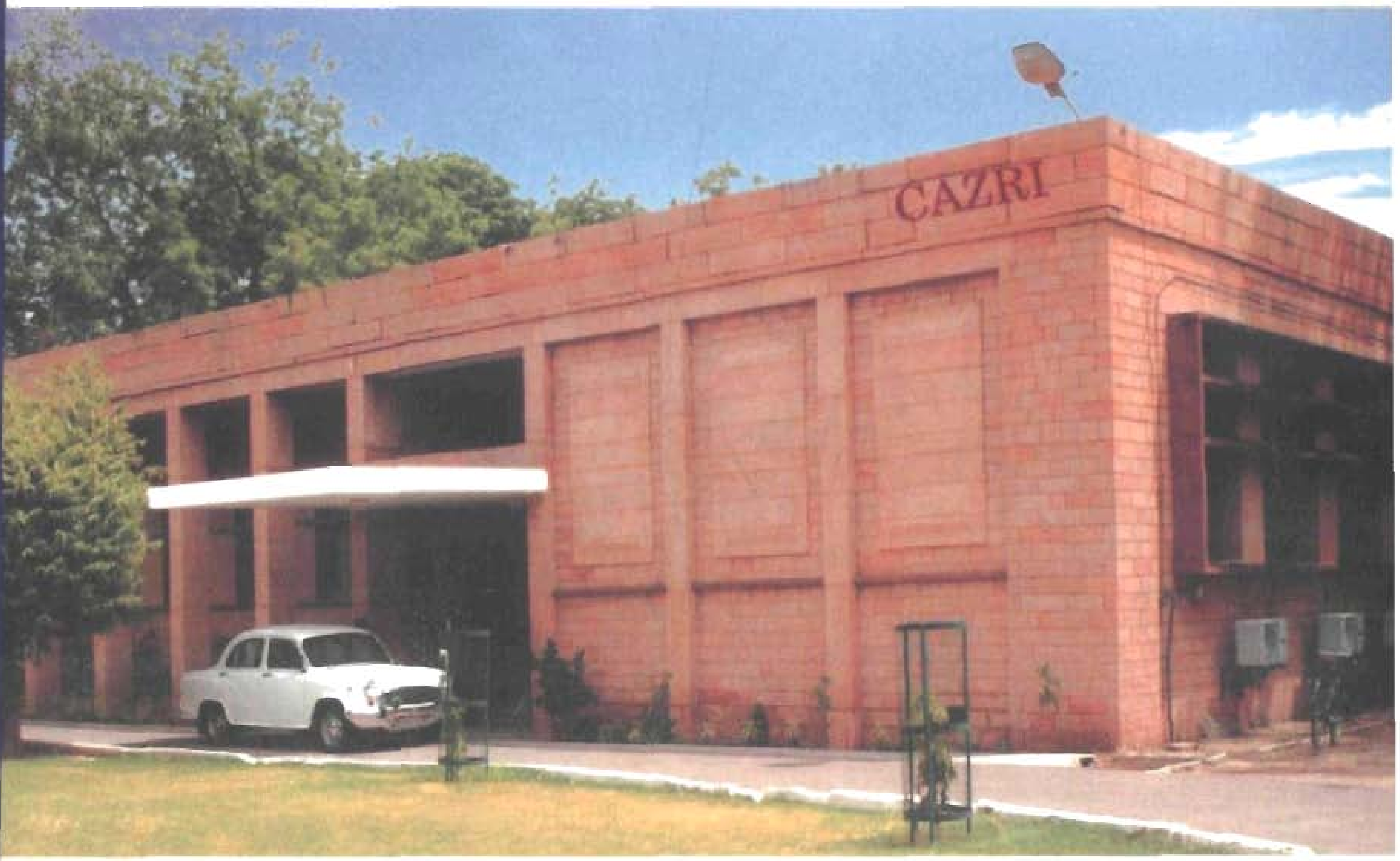

भाकृअनुप
ICAR

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

VISION-2025

CENTRAL ARID ZONE RESEARCH INSTITUTE
(Indian Council of Agricultural Research)
JODHPUR - 342 003, RAJASTHAN, INDIA
Tel. : +91-291-2786584 Fax : +91-291-2788706
E-mail : root@cazri.res.in Website : http://www.cazri.res.in

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Fax	:	+91-291-2788706
E-mail	:	root@cazri.res.in
Website	:	http://www.cazri@res.in

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Director

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FOREWORD

Indian agriculture must continuously evolve to remain ever responsive to manage the change and to meet the growing and diversified needs of different stakeholders in the entire production to consumption chain. In order to capitalize on the opportunities and to convert weaknesses into opportunities, we at the ICAR attempted to visualize an alternate agricultural scenario from present to twenty years hence. In this endeavour, an in-depth analysis of the Strengths, Weaknesses, Opportunities and Threats (SWOT) was undertaken to place our research and technology development efforts in perspective so that we succeed in our pursuit of doing better than the best. Accordingly, the researchable issues are identified, strategies drawn and programmes indicated to have commensurate projects and relevant activities coinciding with the launch of the 11th Five Year Plan.

The arid zones in India are spread to nearly 32 mha accounting for approximately 10% of country's total geographical area. The agriculture in the region is faced with major constraints such as rough climatic conditions (low and erratic rainfall and recurrent droughts) and predominantly sandy soils with low fertility. Fortunately, Indian desert has rich endowment of natural resources in form of abundant sunshine, drought-hardy perennial grasses and trees, domestic livestock animals like goats, sheep, camels, cattle, etc. The over-exploitation of natural resources has triggered degradation and diversification. Looking to the magnitude and complexity of the problems to sustain agriculture in this fragile environment an integrated approach in technology generation and dissemination is called for. The Central Arid Zone Research Institute (CAZRI) is a unique multi-disciplinary Institute that has generated large number of need-based, viable and cost-effective technologies. The Institute has to shoulder a major responsibility to make agriculture in the region stable, productive and viable considering that country looks forward to rainfed areas for quantum jump in food production.

It is expected that realizing the Vision embodied in the document would further ensure that the CAZRI, Jodhpur continues to fulfill its mandate to make Indian agriculture locally, regionally and globally competitive. The efforts and valuable inputs provided by my colleagues at the ICAR Headquarters and by the Director and his team at the Institute level for over a year to develop Vision 2025 deserves appreciation.

(MANGALA RAI)

Secretary, Department of Agricultural Research & Education

and

Director General, Indian Council of Agricultural Research

Dr. Rajendra Prasad Road, Krishi Bhawan, New Delhi 110001, India

March, 2007

PREFACE

Central Arid Zone Research Institute is engaged in research related to problems of arid region for the past five decades, predominantly in the states of Rajasthan and Gujarat and to a little extent in Haryana, Punjab, Andhra Pradesh, Karnataka, etc. In this period the Institute has developed through interdisciplinary approaches a number of technologies, many of which have been disseminated to the stakeholders, contributing to sustainable management of the arid lands. However, increasing human and livestock population is leading to exploitation of the limited resources, thus hastening the land degradation. With overexploitation of limited groundwater, 80% area in arid Rajasthan is now under gray or dark zone. Although the Himalayan water through IGNP has eased the water problem, it has also resulted in water logging and soil salinization. Other environmental problems are also cropping up. A number of useful flora and fauna are threatened to the verge of extinction, and pest scenario is changing. Infrastructural developments are leading to more affluence in the region, while the low-yielding farming systems are being threatened for land, manpower, other resources and overall profitability. As the market is becoming global, opportunities and threats are also being felt for the local agri-products. Therefore, farmers are asking for diversification to high-value crops to final marketable products in a chain format. Choice of crops, though, is not always environment-friendly. 'Profitability' is gradually replacing 'productivity' as the key word.

Another concern for the region is climate change for the worse with increasing drought frequencies that may upset the present crop calendars. Since the prevailing climate has an average of 3 drought years in 5, even a 5% negative deviation in rainfall or a slight increase in temperature may make a lot of difference to agricultural efficiency. In other words, a slight negative change in climate will have an amplified effect on the region's food production and further jeopardise the already vulnerable nutritional security and rural livelihood. To meet these challenges, therefore, we have to reorient our perspective on research, fine-tune some ongoing ones, and undertake new researches.

In view of this, an exercise was initiated by my predecessor Dr. Pratap Narain to review and update the Vision-2020 document, which was prepared a decade ago by Dr. A.S. Faroda. Several drafts of the document were reviewed by a number of distinguished scientists, including Dr. J.S. Samra, DDG, ICAR, Dr. J.S.P. Yadav, Chairman, RAC, Dr. I.P. Abrol, Chairman, SAP, and other eminent members of the RAC and SAP. The reviewers' useful input was incorporated. I am grateful to them for their valuable contributions.

I am highly grateful to Dr. Mangala Rai, Secretary, DARE, Govt. of India and Director General, ICAR, for consistent guidance and encouragement, and always providing exceptionally thoughtful suggestions and directions to improve upon the document. I am also grateful to DDG, ICAR, who critically reviewed the draft documents, and suggested many changes.

Dr. Amal Kar, Dr. S. Kathju and Dr. Manjit Singh carried out compilation and editing of several draft versions of the document to its final shape, for which they deserve my heartfelt sincere thanks. I also thank Dr. B.L. Gajja, Dr. P.C. Moharana, Dr. Balak Ram, Dr. Anurag Saxena and their technical staff members for timely help with data and maps, and Dr. J.C. Tarafdar for going through the final draft. I thank all the Heads of Divisions and Heads of Regional Research Stations, RC&MS as well as their staff members for their whole-hearted efforts to update the document, and the Administration and Accounts for proactive action to get it printed in time. Shri S.B. Sharma did the final page formatting of the document for printing, and Shri V.K. Jayalwal took the cover photographs for which I thank them.

CAZRI dreams of sustainable arid land management through farming systems approach to provide better livelihood to the desert inhabitants, and at the same time to maintain economically exploitable green cover that improves the desert environment. This document provides a brief account of how we propose to achieve that dream under the fast changing scenarios.

(KPR VITTAL)
Director

CONTENTS

Foreword

Preface

Executive Summary

1	**Preamble**	**1**
2	**Mandate**	**3**
3	**Growth of the Institute**	**4**
	Milestones in establishment	4
	Infrastructure	4
4	**Major Achievements**	**11**
	Natural resources appraisal	11
	Water management	16
	Land management	17
	Tree introduction and improvement	19
	Dryland farming	20
	Arid watershed management	22
	Livestock management	23
	Plant and animal by-products	23
	Agricultural engineering and energy management	24
	Socio-economic evaluation and extension activities	25
	Summary of technologies available for transfer	26
5	**Impact Assessment**	**31**
	Major technologies	31
	Input/output assessment	34
	Lessons learnt, suggestions and options for future	37
6	**Scenario: Present and Future**	**40**
	Present scenario	40
	Future scenarios	45
	Implications for future research needs	52
7	**Perspective – A Way Forward**	**53**
8	**Issues**	**58**
	Natural resources monitoring	58
	Plant improvement	60
	Crop production strategies	62
	Livestock production	65
	Integrated farming systems and water management	67
	Farm machinery and energy management	70
	Technology dissemination, capacity building and impact analysis	71
	Agriculture-based livelihood	74

9	**Programmes**	**77**
10	**Linkages, Coordination and Execution Arrangements**	**83**
	Linkages	83
	Training	83
	Coordination arrangement	84
	Execution arrangement	84
11	**Critical Inputs**	**85**
12	**Risk Analysis**	**86**
	SWOT analysis	86
13	**Review**	**89**
	System for reviewing CAZRI's activities	89
	Strength of CAZRI's research	89
	Capacity building of the Institute	90
14	**Resource Generation**	**91**
15	**Outputs**	**92**
16	**Outcome**	**93**
Annexure I		94

EXECUTIVE SUMMARY

The Indian hot arid zone covers 31.7 million ha (Mha), i.e., about 10% of the country's geographical area. Land productivity and life support systems in this fragile ecosystem are adversely affected by environmental constraints such as low and erratic rainfall (100-420 mm $year^{-1}$), high temperatures (45-50°C), high wind speed (30-40 km h^{-1}), high evapotranspiration (1500-2000 mm $year^{-1}$), light textured soils having poor fertility and low water retention capacity, as well as scarce water resources, brackish groundwater, and declining water table. These low-yielding systems are perpetually under stress due to ever rising human and livestock population, frequent droughts and desertification. Local inhabitants over the generations have evolved traditional wisdom, that includes rain water harvesting and its conservation, appropriate landuse compatible with resources, livestock and tree-based farming systems, pastoralism and migration in search of food, feed and livelihood to sustain under these harsh environments. Of late, these traditional systems are dwindling and proving inadequate in the light of modernization, globalization and competition from neighbouring states endowed with better natural resources and infrastructural development.

Efforts to enhance productivity of drylands might put further stress on already depleted natural resources in arid ecosystem. New issues of management of land, water, vegetation, livestock and pest control are likely to crop up. Arid regions world over subsist on low productivity due to abiotic stresses. Enhancing biotic productivity of crops, trees, shrubs, grasses, pastures and livestock by increasing inputs of water, fertilizers and planting material might influence arid environment in totality. Such developments have to be addressed by redefining the mandate with commensurable focus on research and development programs of Central Arid Zone Research Institute. National policies of bringing more water through canals might bring in huge quantity of additional water to arid region. This may lead to a paradigm shift in fauna and flora, crops and cropping systems, farming systems, water-logging and salinization, outbreak of diseases and pest, socio-economic conditions, and a host of second generation issues. It may not be out of place to infer these changes from IGNP experience, and take safeguard action against the possible adverse impacts.

A greater threat that may impact agriculture is climate change due to anthropogenic reasons. Rise in diurnal and seasonal temperatures, higher atmospheric CO_2 levels and shifts/decline in rainfall pattern are expected to put traditional agriculture and developed technologies to severe test.

Keeping these in view, CAZRI proposes to reorient/fine-tune its research strategies to develop high quality need-based programmes in a mission mode. This Perspective Plan is a humble effort in this direction. The plan particularly focuses on farming systems approach and on-farm research. In order to convert constraints into advantages and opportunities the plan envisages concerted research efforts centered around 16 major programmes listed below:

- Integrated resource monitoring using GIS and remote sensing for land use planning
- Monitoring of drought and desertification, vulnerability and early warning system

- Erosion process modeling
- Plant Biodiversity and improvement using conventional and molecular approaches
- Drought physiology and agro-techniques
- Integrated nutrient management and micro-flora for improving productivity
- Integrated pest management in farming systems
- Feed and health management of livestock
- Livestock-based alternate land management systems
- Rain water harvesting, conservation and efficient utilization
- Rehabilitation and management technologies for degraded lands
- Efficient tools and implements for dryland farming
- Appliances for solar and renewable energies
- Post-harvest and value addition to farm produce
- Socio-economic monitoring and impact assessment
- Technology dissemination and human resource development.

To accomplish the desired results Government Organisations (GO), Non-government Orgainsations (NGO), farmers and other stakeholders and financial institutions have to work in a consortium mode to upscale factor productivity in a sustainable mode. The country is looking forward to augment the food grain production through second Green Revolution. This will only be possible through hitherto not fully explored rainfed regions, adopting innovative technologies, post-harvest value addition and developing market chains in a competitive world market.

1. PREAMBLE

In five decades since independence, India has achieved a quantum jump in food grain production through Green Revolution. From barely 60 million tonnes in 1950 the production reached 205 million tonnes in 2002, which was sufficient to feed the population. However, future projections suggest that rising trends in population would necessitate production of at least 307 million tonnes by 2020, i.e., an increase of 102 million tonnes from the land that is now showing signs of diminishing returns with the inputs at the current technological level. It is expected that 64 million tonnes would be contributed from irrigated lands while the remaining 38 million tonnes has to be reaped from the rainfed lands. This calls for a second Green Revolution, which is possible mainly through managing the hitherto not fully explored rainfed regions, as well as application of innovative technologies, post-harvest value addition and developing market chains with indigenous species in a competitive world market.

Enhancing productivity and sustainable production from rainfed drylands, of which arid region is a significant component, has, therefore, become a national agenda. This is reflected in the 53rd resolution of the National Development Council (May 2007) that "resolves that agricultural development strategies must be re-oriented to meet the needs of the farmers and calls upon the Central and State governments to evolve a strategy to rejuvenate agriculture"........."incentivise States to draw up plans for their agriculture sector more comprehensively, taking agro-climatic conditions, natural resource issues and technology into account, and integrating livestock, poultry and fisheries more fully". In this context, the research and development issues of arid region, especially for achieving the targets set for food and feed production in the country through farming systems approach, diversification of agriculture and conservation of natural resources, are some of the challenging issues. The task is formidable, not only because of the rising population, poor resource base and weak resilience capacity of the fragile arid ecosystem, but also because of the threat from Global Warming that predicts a 2-5°C rise in temperature in the region, a more aberrant monsoon behaviour, and a further rise in atmospheric CO_2 and other greenhouse gases, which will impact the agricultural production system.

The Indian hot arid zone covers 31.7 million ha, i.e., about 10% of India's geographical area. Land productivity and life support systems in the region are seriously constrained by environmental limitations such as low and erratic rainfall (100-450 mm year^{-1}), high temperatures (45-50°C), high wind speed (30-40 km h^{-1}), high evapo-transpiration (1500-2000 mm year^{-1}), sandy soils having poor fertility and low water retention capacity, as well as scarce water resources, brackish groundwater and declining groundwater table, all of which severely limit productivity from the system. These low-yielding systems are perpetually under stress due to increasing population of both humans and livestock, and frequent drought and desertification. For livelihood under such a difficult environment, local inhabitants evolved traditional wisdom that included rainwater harvesting and its conservation, land fallowing, livestock- and tree/shrub-based farming systems, and pastoralism and migration in search of food, feed and occupation. The region is bestowed with abundant land, solar and wind energy, rich biodiversity, adapted drought-hardy livestock and traditional wisdom to sustain livelihood under extremes of adversities. Of late, the traditional systems are dwindling and proving inadequate in the externalities of modernization, globalization and competition from neighbouring states that are better endowed with natural resources and infrastructure.

The cultivated land (including current fallow) in arid western Rajasthan during 2001 was 12.2 Mha (58.7%; includes 5.3% current fallow), with an average productivity of pearl millet 0.61 t ha^{-1}, clusterbean 0.28 t ha^{-1}, and moth bean 0.24 t ha^{-1} (botanical names of the cultivated crops are given in Annexure-I). With good management practices, a small increase of 10-12% of the achievable potential of these crops will make a large difference on total factor productivity. Similarly, a slight gain in productivity of the vast livestock population would ensure better income. There is also good scope for furthering medicinal and aromatic plants, cash crops, condiments and spices that are endemic to the region.

Central Arid Zone Research Institute (CAZRI), which was established in October 1959 by the Government of India, and handed over to the Indian Council of Agricultural Research (ICAR) in April 1966, is carrying out systematic research on use and management of natural resources, sustainable farming systems, livestock production and management, and related rural livelihood issues for the last five decades to generate location-specific technologies that can provide solution to the arid zone problems and control desertification. It has produced a number of need-based, viable and cost-effective technologies, demonstrated these to the stakeholders, developed capacity building of the rural masses through training and education, and transferred several technologies to the stakeholders through various development programmes launched by the Govt. of India/ICAR from time to time. The major programmes included the Drought Prone Area Programme (DPAP), launched in 1972, Desert Development Programme (DDP), initiated in 1978, field demonstrations through KVKs (since 1984), ICAR Model watershed development (from 1985), Arid Watershed Management (from 1986), DDP-Transfer of Technology (1994) and Institute Village Link Programme (IVLP, from 1996). The research efforts are continuing in collaboration with different national and international agencies.

With time it has been realized that some areas of research need more attention, or a shift in approaches. The approaches to address the enormity and complexity of problems and issues involved in the arid ecosystem are:

- Focused and time-bound research for development programmes.
- Emphasis on on-farm research and fine-tuning of technologies for enhancing productivity and sustainability through development of integrated farming system models.
- Diversification of agriculture through high-value crops, such as medicinal, aromatic and petro-plants/crops.
- Development and production of improved seeds and quality planting materials that demand less water.
- Developing market-driven R&D strategies and value-added chains involving public-private partnership for higher profitability.
- Close involvement of clients, GOs, NGOs, and line departments in planning, implementation and monitoring of programmes through consortia approach.
- Networking, sharing of information and resources through well set out linkages to invoke inter-institutional and regional collaboration for synergistic benefits.

These issues are addressed in the present Perspective Plan of CAZRI.

2. MANDATE

The mandate of CAZRI has been updated from time to time as per changing needs of arid ecosystem and at the recommendations of various committees. Mandate followed since 1994 is as follows:

- To undertake basic and applied researches that will contribute to the development of sustainable farming systems in the arid ecosystem
- To act as repository of information on the state of natural resources and desertification process and its control
- To provide scientific leadership and collaboration with State Agricultural Universities for generating location-specific technologies for achieving the objectives
- To act as a centre for training in research methodologies in relevant scientific areas
- To collaborate with relevant national and international institutions in achieving the above objectives
- To provide consultancy.

Globalization and changes in life styles are likely to create demand for a variety of products and facilities, and the market driven forces are expected to cause a shift in production systems, as well as put pressure to close the yield gaps. A national focus on enhancing productivity of drylands might put further stress on the limited natural resources of arid region. Enhancing productivity of crops, trees, shrubs and grasses, including that of medicinal plants and pastures, through higher inputs of water, nutrients and improved planting material, might favourably influence the delicately balanced arid environment. Bringing more water into the arid zone through inter-basin transfer may lead to a further paradigm shift in fauna and flora, crops and cropping system, farming systems, etc. of the region, but new problems of diseases and pest, water logging and salinization, socio-economic changes and a host of other second-generation issues are also likely to come up, requiring more focused attention towards resource management. It may not be out of place to predict/forecast these changes through the post-Indira Gandhi Nahar Paryojana (IGNP) experiences, and safeguard against adverse impacts of inter-basin water transfer.

Apart from the pressure of increased market demand, the global climate change is also likely to impact the agricultural scenario of arid region. Unless preventive measures are taken, the agricultural land in India is likely to gradually shrink due to warming of the environment and moisture stress. In arid zone much of the present croplands may not be suitable for cropping for too long. Faster melting of the Himalayan glaciers may eventually reduce irrigated area in north India. Even though average annual rainfall has not changed significantly in western Rajasthan so far, the temperatures are playing havoc, as not only the diurnal temperatures are increasing, but also the summer and winter temperatures. With these changes the extreme weather events are also increasing since the last decade. These externalities are affecting crop production. Hence, assessing the impacts of climate change and developing technologies to mitigate the impacts would be of vital consideration for sustaining livelihood of the rural communities. Mandate of the Institute needs to focus on the short-term and long-term requirements based on scenarios unfolding.

3. GROWTH OF THE INSTITUTE

MILESTONES IN ESTABLISHMENT

Central Arid Zone Research Institute (CAZRI), had a humble beginning in 1952 when, alarmed by the apprehension that the desert in Rajasthan might spread to Delhi and other parts of India, Government of India established a Desert Afforestation Research Station at Jodhpur, to carry out research on stabilization of sand dunes and establishment of shelterbelts for containing wind erosion. In 1957, this station was reorganized as Desert Afforestation and Soil Conservation Station. On October 1, 1959 Government of India, on the advice of Dr. C.S. Christian, a UNESCO expert from CSIRO, Australia, reorganised the Station into a major centre for arid zone research, called the Central Arid Zone Research Institute. While proposing the Institute, the guiding principles were spelt out as study of fundamental aspects of the problems and development of principles of control measures. More focus was laid on a holistic approach that recognizes the fragility of the arid landscape and strength of the region in mixed agriculture, consisting of both crops and livestock. In other words, the Institute was created for research addressing the environmental and livelihood-based issues of the region, with emphasis on conservation agriculture. This was one of the first International Institutes of its kind funded by UNESCO under its programme of International Studies on Arid Zones. On April 1, 1966 CAZRI was brought under the administrative control of Indian Council of Agricultural Research.

INFRASTRUCTURE

Agro-climatic setting of research farms

CAZRI has its headquarters at Jodhpur, and four Regional Research Stations at Bikaner, Pali, Jaisalmer (in Rajasthan) and Kukma (near Bhuj in Gujarat). There are also five Experimental Areas attached to Jodhpur, Pali and Jaisalmer stations for studies on Rangeland Management. The research farms are located in different edapho-climatic situations to study essentially the 28.57 m ha hot arid zones in Rajasthan, Gujarat, Haryana and Punjab (Fig. 1). The major agro-climatic regions covered under these four states are: (1) Trans-Gangetic Plain Region (in Punjab, Haryana and north-west Rajasthan), (2) Western Dry Region (in the western districts of Rajasthan, covering the Thar Desert), and (3) Gujarat Plains and Hills Region (in Kachchh and Saurashtra, covering the Great Rann of Kachchh also). The immense natural resource variability in these regions, as well as the Indira Gandhi Nahar Paryojana (IGNP) in the very dry western districts of Hanumangarh, Ganganagar, Bikaner and Jaisalmer in Rajasthan (Fig. 2), the other canal systems in Ganganagar and adjoining districts of Punjab and Haryana, and the likely commissioning of the Narmada Canal system in Saurashtra and Kachchh districts of Gujarat and in Barmer and Jalor districts of Rajasthan, offer an unique opportunity for location-specific problem-solving research and multi-location testing of technologies. The agro-climatic zones provide some of the excellent field laboratories in arid region for research. The agro-climatic settings of the headquarters and the Regional Research Stations are given in Table 1.

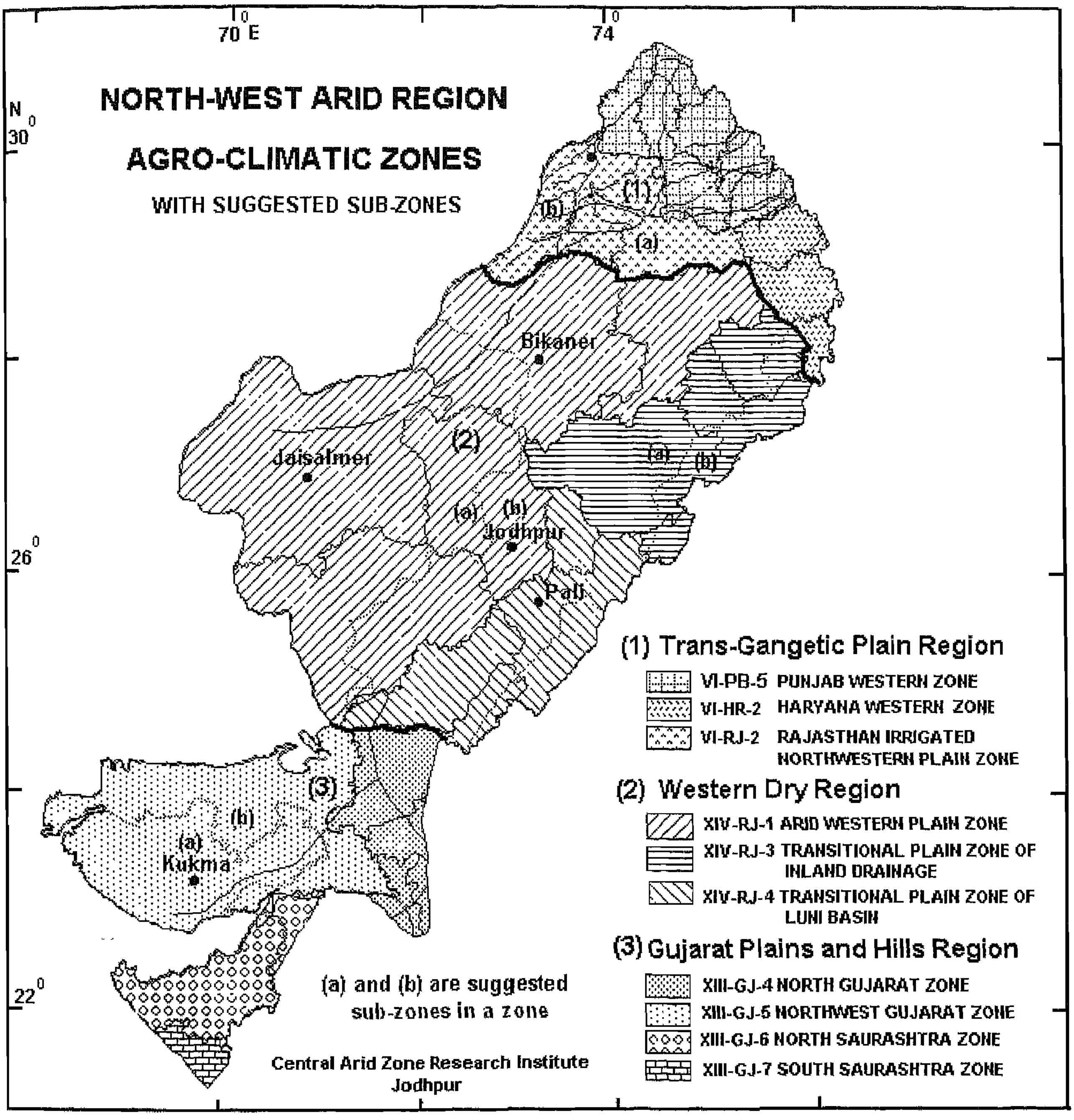

Fig. 1. Agro-climatic regions and zones in north-west arid zone of India.

CAZRI takes pride in developing 52 research areas for silvopasture, conducting elaborate grazing studies and handing over all except the above experimental areas to the Government of Rajasthan. In 2005, CAZRI handed over 40.46 ha land at the Headquarters to the Ministry of Health for construction of a hospital under the All India Institute of Medical Sciences.

Table 1. Agro-climatic setting of CAZRI research stations and their mandated areas

Center	Annual rainfall (mm)	Agro-climatic zone, major topography and soil types	Major water resources of the region	Major activities
Headquarters				
Jodhpur Area: 241 ha	370	Arid Western Plain; but mandated for all the arid agro-climatic zones	Locally potable groundwater, over-exploited due to irrigation; major surface water conservation from IGNP Lift at Jodhpur for drinking	Natural resources monitoring, desertification control, developing sustainable farming systems and alternate farming; improving energy use efficiency; HRD and technology transfer
Regional Research Stations				
Pali Estd: 1953 Area: 454 ha	415	Transitional Plain of Luni Basin; alluvial plains; sandy loam, saline/sodic	Brackish to saline ground water, surface water conservation at few medium irrigation reservoirs	Management of saline/sodic soils; location- specific farming systems research; seed production of trees and grasses; technology transfer
Bikaner Estd: 1987 Area: 263 ha	260	Arid Western Plain & Irrigated North-western Plain; dune and interdune plains, alluvial plains; sandy loam to loamy sand; saline	Potable to brackish groundwater; Canal irrigation (IGNP, Gang Canal); Nadis getting disused even in non-command areas due to pipe water supply	Integrated farming system research with focus on silvopasture and livestock management; management of water logged, salt-affected command areas; biodiversity conservation; technology transfer
Jaisalmer Estd: 1959 Area: 1031 ha	190	Arid Western Plain; rocky/ shallow gravelly plains, sand dunes and interdune plains; sandy loam, shallow miscellaneous	Potable groundwater mainly from Lathi aquifer; also IGNP; rainwater conservation (*Nadis, Khadins,* etc.)	Research on *Lasiurus sindicus* -based silvo-pastoral system and *khadin* cultivation; biodiversity conservation; seed production of trees and grasses; technology transfer
Kukma Estd: 1987 Area: 58.53 ha	340	North and North-west Gujarat Plains and Hills; hills, colluvial plains, coastal plains and Ranns; sandy loam to clay-loam, saline/sodic	Groundwater potable to saline; surface water conserved in several dams for minor irrigation	Evaluation of suitable farming systems for shallow and saline/sodic soils; seed production of trees and grasses; water harvesting; technology transfer

The characteristics of the five Experimental areas are provided in Table 2.

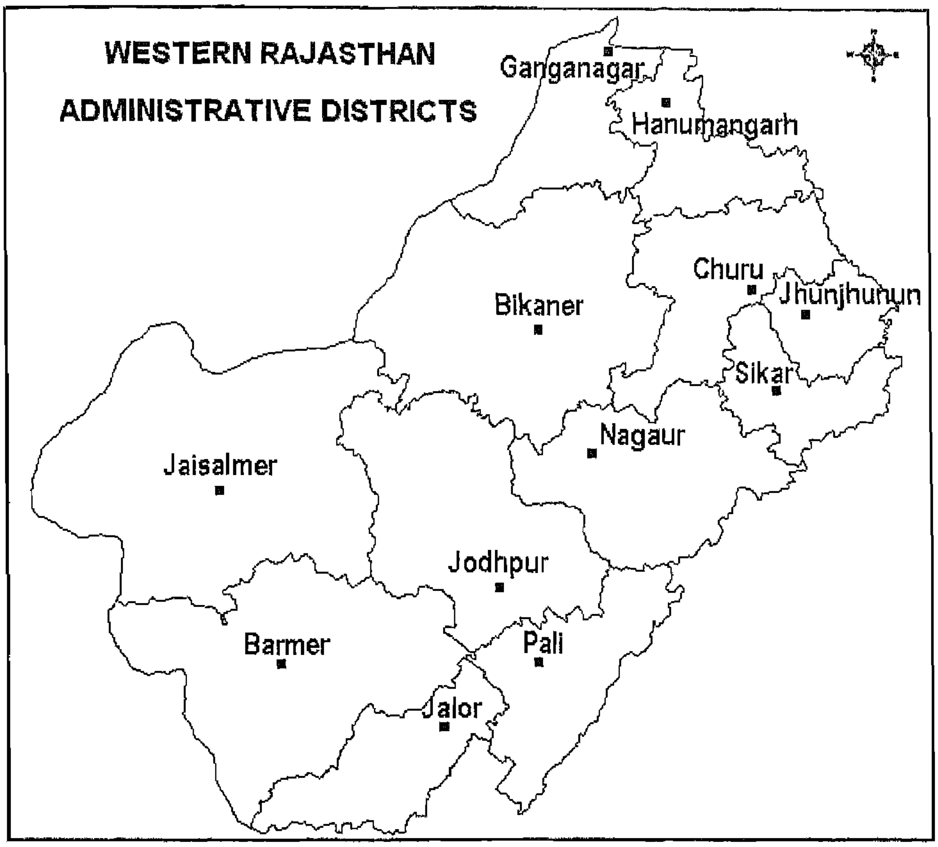

Fig. 2. Administrative districts in western Rajasthan.

Table 2. Experimental areas of CAZRI and their activities

Experimental Area	Annual rainfall (mm)	Major topography and soil types	Major activities
Kailana Estd: 1958 Area: 311.32 ha CAZRI, Jodhpur	370	Rocky, sandy loam	*Acacia senegal*-based silvo-pastoral system; tree seed/ gum production
Beri Ganga Estd: 1958 Area: 262.68 ha CAZRI, Jodhpur	370	Rocky, sandy loam	Silvo-pastoral system research; biodiversity conservation
Bhopalgarh Estd: 1958 Area: 51.40 ha CAZRI, Jodhpur	325	Rocky, shallow sandy	Range management and silvo-pastoral system
Jadan Estd: 1958 Area: 76.89 ha RRS, Pali	415	Shallow sandy loam, saline/ sodic	Integrated watershed management; seed production of grasses; studies on medicinal and high value plants
Chandan Estd: 1958 Area: 95.10 ha RRS, Jaisalmer	190	Sandy	Integrated farming system research, efficient use of groundwater, wind erosion measurement

Organisation

The Institute stands second in manned personnel among the agricultural research institutes in the Council. A sanctioned strength of 196 scientists in the Fourth Five-Year Plan was reduced to 147 by the Tenth Five-Year Plan. The range of disciplines coverers the branches of agriculture, animal husbandry, socio-economics and basic sciences. The present strength (as on 1 August 2007) is only 98 from 27 disciplines, including Director. The Institute is now organized in the following seven Divisions at the Headquarters at Jodhpur: Natural Resources and Environment, Integrated Land Use Management and Farming Systems, Soil-Water-Plant Relationship, Plant Sciences and Biotechnology, Animal Sciences & Forage Production, Agricultural Engineering and Energy, and Agricultural Economics, Extension and Training. It also hosts two National Network Projects, one on Rodent Control and another on Arid Legumes. Two Krishi Vigyan Kendras at Jodhpur and Pali (with training facilities for farmers) lend additional support to transfer of technologies and outreach programmes of the Institute. A Research Coordination and Management Section (RCMS) helps Director to coordinate the research. Organogram of the Institute is given in Fig. 3.

Buildings

Beginning with a modest building of its own in 1964, housing the office of Director, Library, Administration, a few Laboratories, a small auditorium and a modest museum, the headquarters at Jodhpur could add more buildings from 1975 onwards, housing the different research Divisions, the Library and the administration and accounts wing, the last one being inaugurated in 2003. A building for KVK was constructed in 1988 and the Farm Management block came up in 1989. The Guest House (International Hostel) was expanded in 2001. To meet the requirements of trainings, seminars, symposia, etc., a conference hall facility was created in the main building, while another seminar hall was constructed at the International Hostel. A Farmer's Hostel and a Training Hostel accommodate the farmers, trainees, and research students. A separate building constructed in 2002, housing the Agricultural Technology Information Centre (ATIC), caters to the demands of farmers and other stakeholders. The campus houses the offices of the regional station of NBPGR, the Regional Remote Sensing Service Centre of Indian Space Research Organisation (ISRO), and the Zonal Coordinator of KVK (Zone VI). The facilities at CAZRI campus are synergistically utilized and shared by all the Institutions located in the town. This campus is also among the selected five in the country where the ICAR conducts its Zonal Sports.

For Regional Research Stations, modest office and laboratory buildings were constructed at Pali and Bikaner in 1980, and at Jaisalmer and Kukma in 1995. The buildings at Kukma suffered irreparable damage during the 2001 earthquake, so a new building was constructed during 2006.

Laboratories

Over the years, the Institute has developed well-equipped and spacious laboratories catering to the needs of advanced research in wide-ranging disciplines, including natural resource assessment through remote sensing and GIS, soil analysis, hydrology, agro-meteorology, organic chemistry, biotechnology, plant physiology, pest management, agroforestry, silviculture, animal nutrition and physiology, product processing, solar energy, etc. Livestock sheds for both small and large ruminants have also been constructed.

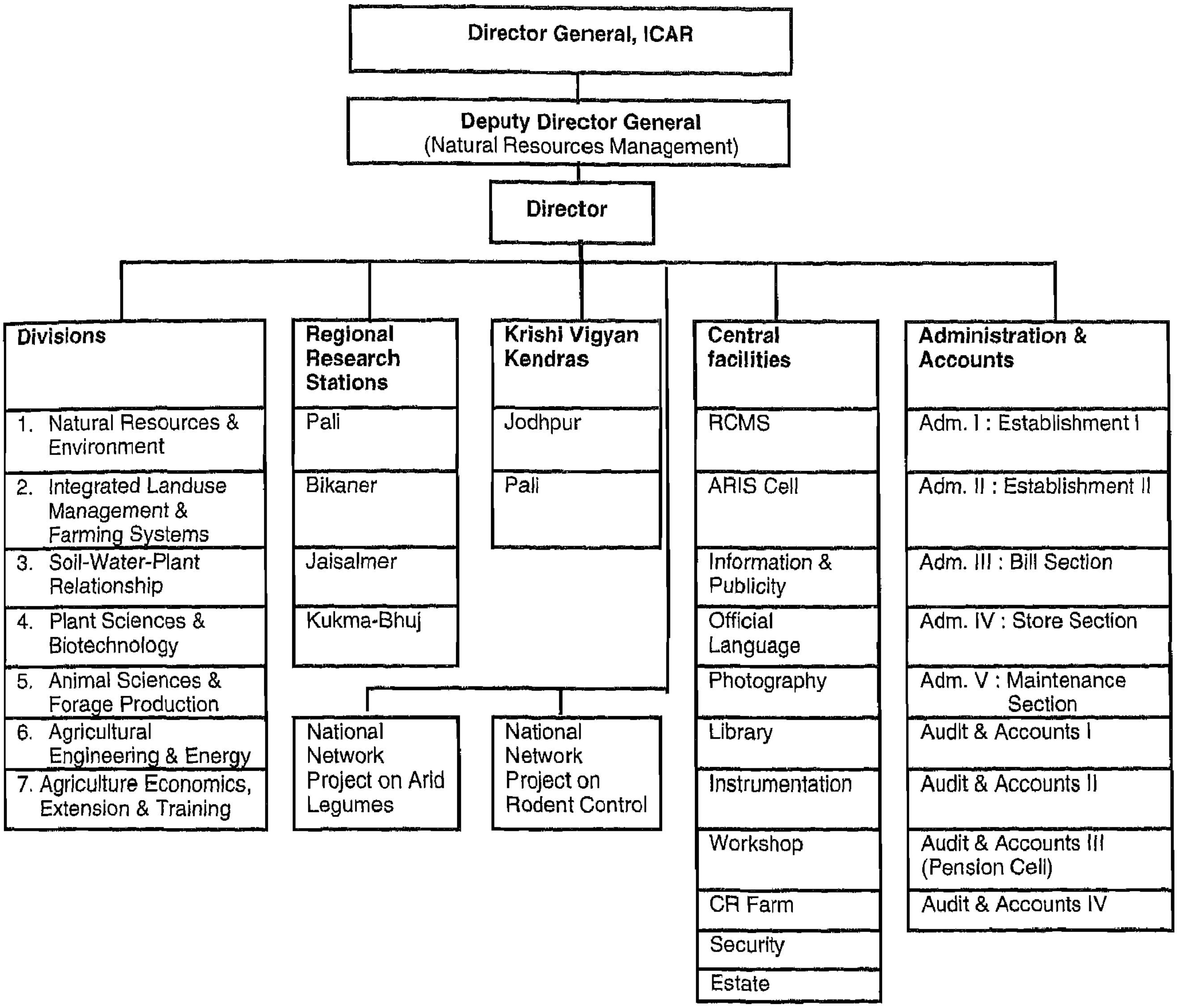

Fig. 3. Organizational Structure of Central Arid Zone Research Institute.

Library

A spacious Library building came up in 1992. With a modest collection of 800 books in 1959, the Institute library is now one of the best of its kind in the arid region. It has more than 21,000 books and 56000 back volumes of journals. Currently it subscribes to 170 national and international journals, and two international databases, AGRIS and CABI. Facilities exist for computerization and reprography. The library runs the country's Ministry of Environment and Forest's only centre for dissemination of information on desert environment, and publishes a newsletter, DEN News.

ARIS

The Institute is a part of the ICAR-wide network of information gathering on human resources. Its computer hub at the ARIS (Agricultural Research Information System) Cell is working with the IASRI-developed software, PERMISNET. It hosts the Institute's website, highlighting its activities, research programmes, achievements, etc. ARIS also provides the scientists and other officers e-mail and internet services, and manages the local network.

Plan-wise budget and manpower

The budget expenditure of CAZRI is shown in Tables 3.

Table 3. Budget of CAZRI (Rs. Lakh*)

Plan	Plan	Non-plan	Others	Total
II	56.19	26.51	-	82.70
III	55.44	-	0.06	55.50
IV	107.45	15.54	7.43	130.42
V	207.21	185.56	16.41	309.18
VI	551.92	285.18	-	837.10
VII	245.40	1249.60	53.23	1548.23
VIII	750.00	2793.18	271.73	3814.91
IX	795.00	5386.75	-	6181.75
X	951.00	9000.00	-	9951.00
XI**	100.00	10000.00		11000.00

* 1 Lakh= 0.1 million; **projected.

The sanctioned manpower of the Institute is given in Table 4.

Table 4. Sanctioned manpower of CAZRI

Plan	Scientific	Technical	Administrative	Auxiliary/ Supporting
V	174	225	100	-
VI	196	235	90	-
VII	191	283	123	50
VIII	150	290	130	52
IX	149	304	111	247
X	147	304	111	247
XI*	147	304	111	247

* anticipated.

4. MAJOR ACHIEVEMENTS

CAZRI is a unique multi-disciplinary institute established to evolve solutions/ technologies to address the complex problems of arid region, demonstrate their viability through on-station as well as on-farm research, and train/advise stakeholders for their large-scale adoption in the region. During the 48 years of its existence, CAZRI has contributed to the best of its ability to arid zone research and development, especially for understanding and management of the region's land and water resources, evolving farming systems, improvements of bio-resources, alternate sources of energy, etc. The technologies released for adoption include those for sand dune stabilization and wind erosion control, water harvesting, crop, tree and grassland improvement, dryland farming, arid horticulture, alternate land use strategies, pest management, livestock management, energy management, etc. CAZRI provides regular training and demonstrations to the farmers, state officials, NGOs and other stakeholders, and holds regular exhibitions, for which it has an Extension wing and two Krishi Vigyan Kendras. The institute also hosts the national network projects on rodents and arid legumes, in which several institutes and agricultural universities of the hot and cold arid regions are effectively participating. Following is a brief account of the major achievements of the Institute.

NATURAL RESOURCES APPRAISAL

Resource Survey for Sustainable Development

Since its inception, CAZRI is involved in integrated survey and assessment of natural resources of the Indian arid zone for identification of problems and potentials of land resources and to suggest their sustainable use. So far it has completed the task in more than 26 million hectare area (i.e. more than 83% of the country's hot arid zone) in the states of Rajasthan, Gujarat, Haryana, Punjab and Karnataka. Data on landform, soil, vegetation, surface and ground water, land use and land degradation status, as well as on socio-economic conditions are collected from surveyed areas through remote sensing and detailed ground verification, and integrated into a conceptual framework of Major Land Resources Units (MLRUs) for devising sustainable development plans. A satellite-guided wasteland mapping in eight districts of Rajasthan has revealed 30% area under different types of wasteland. A number of atlases, depicting the potentials and problems of Rajasthan, have also been prepared. The reports and interpretative maps are used by various government and non-government agencies for resource assessment, watershed development, land allotment and other multifarious activities.

Several special, need-based surveys have been carried out by the Institute at village to district and basin levels to cater to the demands of state governments, the most notable being the survey of upper Luni basin for Govt. of Rajasthan, Mahendragarh district (Haryana) for Govt. of Haryana, Abohar tehsil (Punjab) for Union Ministry of Agriculture, and Challakere Taluka for Govt. of Mysore (now Karnataka). Extent of damage to land and water along the Luni, the Jojri and the Bandi rivers due to effluents from textile industries was assessed at the request of Govt. of Rajasthan, which also helped the Honourable High Court of Rajasthan to settle in 2003 a dispute on disposal of effluent water in streams. The Institute has also provided its expertise on integrated resource survey for undertaking various activities, including Integrated Mission for Sustainable Development (IMSD) at national level, land use assessment for Govt. of Rajasthan, Desert Development

Programme (DDP) in villages, Lab to Land programme, Institute-Village-Linkage Programme (IVLP), etc. Institute has also actively participated in drought management of Govt. of Rajasthan, provided trainings on land resources assessment to universities and other institutions, and advised the Government on policy decisions.

Combating drought and desertification

Drought and desertification are major problems of arid zone of India. Desertification mapping through remote sensing and field data has revealed that about 75% area in western Rajasthan is affected by wind erosion/deposition alone, followed by water erosion (11%), salinity/alkalinity (5%) and water-logging (0.7%). About 21% area is affected by desertification of severe intensity, and 40% by moderate intensity, especially due to high human and animal pressures (Fig. 4). Grazing lands have declined by 9-30% during the second half of the Twentieth Century. Causes of the problems have been identified and suitable ameliorative measures are suggested at regular interval.

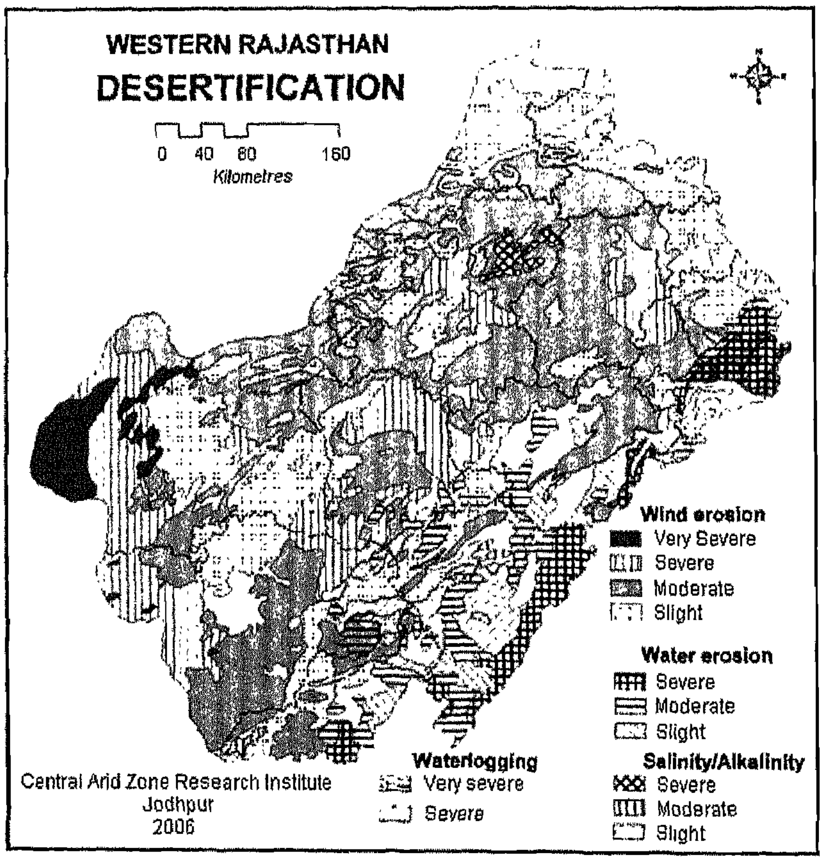

Fig. 4. Desertification map of western Rajasthan.

CAZRI provided valuable services as a member of the National Working Group on Desertification Mapping and Monitoring under TPN-1, as well as on Desertification Control. UN Convention to Combat Desertification (UNCCD) identified CAZRI to co-ordinate the activities of desertification control through agroforestry and soil conservation in Asia under TPN-2. Its experts also provide valuable guidance to different countries. CAZRI has also executed collaborative research with several reputed institutions of developed countries like Australia, Japan, USA, USSR, etc.

Drought is a recurring phenomenon in arid areas. Studies have shown that in western Rajasthan 47 to 62% of the years during the 20th Century experienced drought of some intensity. The periods 1901-10, 1911-20, 1961-70 and 1981-90 recorded higher number of moderate and severe droughts. The worst drought during the recorded history (more than 100 years) occurred in 2002-03. Based on tehsil-level data on meteorological parameters across the country, CAZRI delineated the arid and semi-arid zones of India, which provided the basis for determining DDP and DPAP districts. According to it, areas having a negative moisture balance of –66.6% or higher fall under arid zone, while those having moisture balance of –33.3 to –66.6% are under semi-arid zone.

In order to combat, drought and desertification, and for sustainable arid land management, CAZRI has developed several technologies like sand dune stabilization, shelterbelt plantation, soil and water conservation, improved agro-forestry systems, management of cropland, pasture and range areas, management of saline-sodic soils, and rehabilitation of mine spoils, and is disseminating these technologies to the stakeholders. During the extreme drought year of 2002-03, CAZRI evolved contingency combating plans, discussed the related issues with policy makers and planners in a brainstorming session, and organised as many as 175 training camps with State government, especially for improving the quality of wheat stover, resource generation by women through value-addition to agricultural products, mushroom cultivation, dairying, etc.

Climate change in the Thar Desert

Using deep sedimentary records from sand dunes and sandy plains of the desert and its fringe areas in Rajasthan and Gujarat the dune-forming climates during the last 100 thousand years have been established and the chronology of events reconstructed. It has been established that phases of sand accumulation in the region are positively related to the strength of SW monsoon wind (as opposed to glacial climate), and that the current century-scale rates of human-induced mobility are about 3 times greater than the geological rates. The results provided the academic world with new understanding of the role of monsoon wind in dune formation, climate of the ancient civilizations in north Rajasthan, and tele-connections between climates of the global deserts in a time domain.

Studies on present climatic trends in the region indicated a rising trend in annual mean air temperature at a linear rate of 0.02°C $year^{-1}$ over Jodhpur and 0.01°C $year^{-1}$ over Pali. Statistically significant increasing trend in the annual mean air temperature is also noticed at Barmer in the west and Ajmer in the east. No significant trend was found for rainfall, except some increase at few stations along the eastern margin. Recent incidence of sudden cloudbursts and floods in south and south-eastern Rajasthan and southern Gujarat and recurring droughts in western part of arid Rajasthan, associated with delayed onset or early withdrawals of monsoon are suspected to be a consequence of global warning, which need to be probed.

Sand dunes and their evolution in the Thar Desert

Sand dunes are the dominant landform of the Thar Desert, covering ~58% of western Rajasthan. Nine major dune types have been recognized, which can broadly be grouped under the old dune system and the new dune system. Researches on their morphology and evolution have provided valuable information for control measures. Wind erosion index for different localities in the desert has been calculated, which shows that the severity of potential erosion varies from very low (index: 1-14) in the east to extremely high (480 and above) in the west, which explain the regional-scale wind erosion and dune systems.

Saraswati and other buried rivers in the Thar Desert

In its quest for water, salinity and alluvium CAZRI began locating buried streams of the desert since 1960. Studies have revealed some hitherto unknown early courses of the Saraswati and the Drishadvati rivers of Himalayan origin, as well as former courses of several streams of the Luni drainage system from the Aravalli ranges, which contributed water and alluvium in the region, but are now buried under high sand dunes and sand sheets (Fig. 5). It has been suggested that periods of higher rainfall in the past and the water of the Satadru River (present-day Sutlej) used to sustain the Saraswati river system. The drying of the river system was linked to the shifting of the Sutlej, tectonic disturbances and climate change. This finding has opened the floodgate of new thinking, helped in locating potable groundwater at shallow depth, and explained water logging and salinization in the region. Rajasthan Ground Water Board is now drilling for potable water in the area.

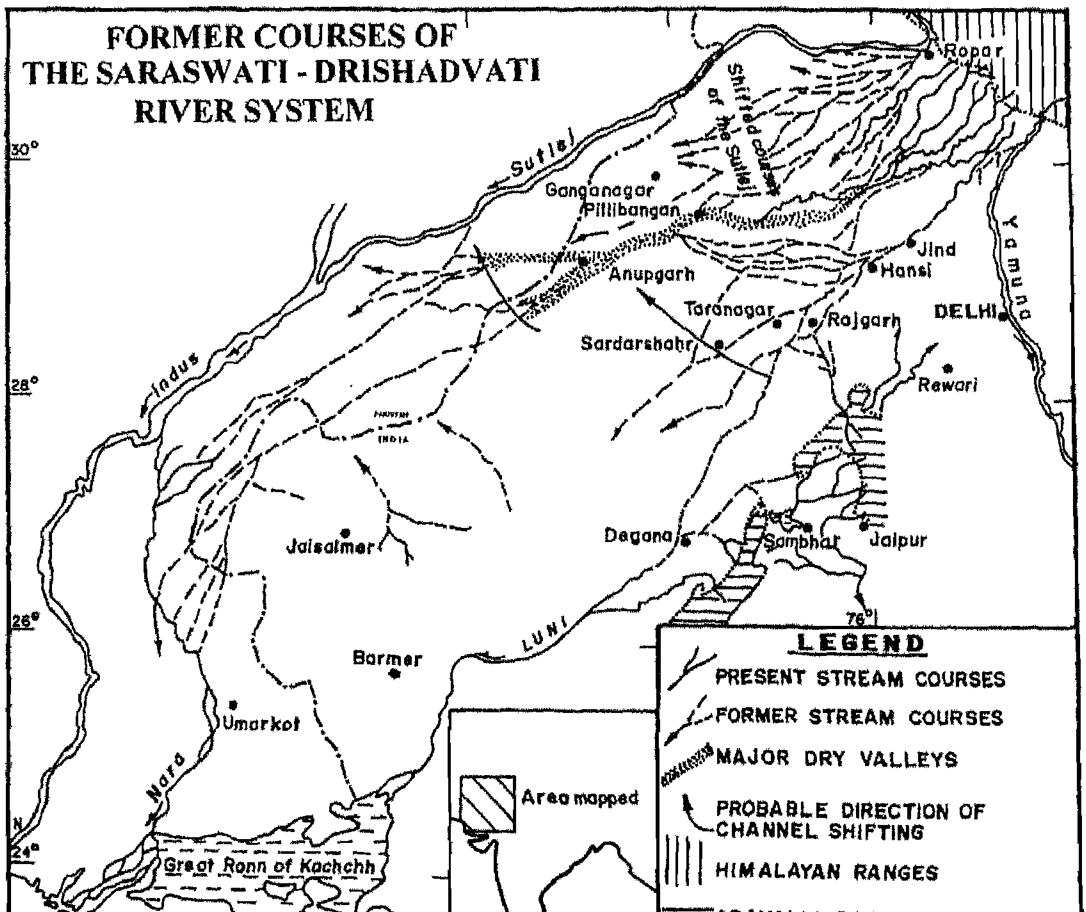

Fig. 5. Saraswati River system through Thar Desert.

Major soil groups and their nutrient status

Four broad groups of soils have been identified in northwestern arid zone: soils of Indo-Gangetic Plains; soils of sand dunes and sandy plains; soils of medium textured alluvial plains; and soils of shallow undulating terrain. Most soils are either Calciorthids, Camborthids, or Torripsamments. The soil profiles have low contents of silt, clay and humus, but higher $CaCO_3$, gypsum and salt contents, dominance of water-soluble salts, and an impervious calcic or gypsiferous hardpan. The soils are mostly low in organic carbon due to sparse vegetation cover, high temperature and coarseness of the particles. In the higher rainfall zones and in areas where clay content in the soil increases, organic carbon content also increases. The soils are deficient in available N and P. Micronutrient contents of the soils are not uniform. Mn and Cu contents are considered adequate, but Zn is deficient in some soils. The dune and sandy plain soils are well provided with various micronutrients.

Medicinal plants of the Thar Desert

The wealth of medicinal plants of Thar Desert has been documented. Out of 116 useful species catalogued, 65 species are used as household remedies, 34 in traditional system of medicine and 17 are commercially exploited. Plants of medicinal and industrial values like *Balanites aegyptica, Commiphora wightii, Euphorbia antisyphilitica, Haloxylon*, *Cassia angustifolia,* etc., have been identified, and their use potentials suggested. Multi-location studies have been intensified on plants like *C. angustifolia*, *C. wightii* and *L. alba*, which have gone to commercialisation. A variety of *Aloe vera*, which is a good source of gel and has high aloin content, has been identified. Detailed chemical properties of *A. vera* are being studied. CAZRI has a garden for medicinal and aromatic plants with focussed research in hand.

Vegetation changes due to overgrazing and protection

Increased grazing pressure on pasture was found to effect a shift in the phenology, leading to gradual disappearance of many species, decline in biomass yield and changes in seed bank. Species richness increased upon moderate grazing pressure, but declined gradually with increasing pressure. On the contrary, 3-5 years' protection to a degraded pasture on rocky wasteland led to considerable increase in self-regeneration of plants, including that of some endangered species, seeding and rapid succession of species. A 5-18 years' closure has been found essential for effective regeneration of vegetation in different habitats. An Indo-Australian collaborative research found that the satellite-derived PD-54 index was a good measure for locating the degraded low vegetation cover in the region.

Climatic control on grassland productivity

Sewan grass (*Lasiurus sindicus*) has been found to have the best water and energy use efficiency among the palatable desert grasses, followed by Anjan (*Cenchrus ciliaris*) and Dhaman (*C. setigerus*). Seed yield of *C. ciliaris* increased from 67 to 153 kg ha^{-1} with a gradual increase in quantum of rainfall from 150 mm to 400 mm. Rainfall at flowering/seed-setting stage reduced the seed yield. Only in good rainfall years, application of N and P to the grass had a significant effect on forage yield. During low rainfall years, *C. ciliaris* had higher dry matter yield, as well as water and energy use efficiency than *C. setigerus*, whereas under high rainfall conditions *C. setigerus* performed better than *C. ciliaris*.

Arid zone hydrology

Studies on rainfall-runoff-recharge dynamics have revealed high variability in runoff generation from different catchments. In small catchment studies, polyethylene sheet generated maximum runoff (93%). Among the roofs, those having corrugated G.I. sheet generated 86% runoff, followed by stone slab roofs (81%), paved surfaces (69%), clay tile roofs (57%) and metal roads

(53%). The lowest runoff efficiency (32%) was from roof made of straw, which generated highly contaminated runoff water. Threshold rainfall to generate runoff for different catchments ranged from 3.1 mm for plastic surface to 9.5 mm for thatched straw roof. The least expensive method of runoff inducement is having a natural catchment with impervious basement. Such studies considerably helped in harvesting of rainwater and its management.

Water balance of the Luni Basin

Studies on hydrological network in the Luni Basin reveal that rainfall-runoff ratio varies from 0.6 in upland areas to 0.2 in down-valley. The trunk streams are subjected to heavy transmission losses in alluvium. The streams usually convey suspended sediment load of 7.5 to 431.9 g L^{-1}. There is high withdrawal of groundwater in the basin, the amount being higher during drought years. Normal monsoon rainfall for 2 to 3 years at a stretch is required to recoup the deficit in one drought year. Probability of 3 consecutive normal rainfall years in the basin is less than 10%.

Evaporation reduction in tanks

Loss of water through evaporation in tanks and reservoirs cause considerable water loss during storage. Floating materials such as polyethylene sheet covering 75% of the water surface reduced evaporation by about 68%, but did not last long, white-painted foamed rubber sheets reduced average evaporation by 76%, and polystyrene sheets, used mainly as packing material, reduced evaporation up to 85%.

Water requirement of arid zone crops

Higher water-use efficiency at 50% potential evapotranspiration (PET), compared to 100% PET, offer considerable scope for optimizing the scarce water for irrigation at a reduced rate and for extending irrigation to larger areas. For optimal use of limited water resources, drip and sprinkler systems of irrigation for different crops have been standardised and popularised. Double-row planting with a lateral in the centre reduced the capital cost and water use by 50%. Initial investment on drip installation is paid off in 2-3 years by increase in yield and growing high value crops. Sprinkler irrigation has been found suitable for most field crops and grasses even on undulating field, leading to considerable saving of irrigation water. One supplemental life-saving irrigation to pearl millet resulted up to 60% increase in grain production.

WATER MANAGEMENT

Water harvesting

Traditional water harvesting systems of arid zone have been improved to enhance their utility and efficiency. Improved designs of *tanka* (cistern; 10,000 to 600,000 litres capacity), *nadi* (pond) with low-density polyethylene sheeting (LDPE) lining, silt trap, etc., and *khadin* (water harvesting structure) have been developed and standardised (Fig. 6). These improved storage structures are being popularised under various Institute and government programmes, including Rajiv Gandhi Drinking Water Mission.

Circular inward sloping catchments of 1-2 m diameter for rainwater harvesting in a plain land proved effective in boosting the growth of various fruit and forest trees while on sloping lands, half moon terraces were more effective. Catchments covered with plastic and sealing with pond silt generated higher runoff for arid horticulture. Lining by a mixture of gypsum and pond silt emulsion reduced the water seepage of irrigation channels significantly.

Water conservation and utilisation

Field bunding, mulching and use of clay as subsurface barrier were found effective for conservation of water in croplands. Vegetative barriers of *Cymbopogon jwarancusa*, *Cenchrus ciliaris* and *C. setigerus* across the slope of cultivated fields proved effective in conserving moisture and increasing crop production. These live barriers are easy to raise, less expensive and provide fodder during the lean period, and hence are becoming popular among farmers.

Use of fly ash (15%) in sandy soils increased the water retention by 35% at 0.1 MPa and by 46% at 0.3 MPa. A double-wall earthen pot, named *Jal tripti*, has been developed for raising tree saplings, which can save water by 80-90%.

Management of land irrigated with sodic water

Many of the water resources in this region are highly saline, while waters low in salinity often contain high residual sodium carbonate (RSC). Irrigation with such water results in sodification of land. To reclaim such lands, gypsum @ 50% of gypsum requirement + the quantity to neutralise the RSC in excess of 10 me L^{-1} was recommended for good grain yield. The technology has been demonstrated in many problem villages of western Rajasthan, and is now becoming popular in view of easy availability of gypsum in the region.

LAND MANAGEMENT

Sand dune stabilisation

Sand dunes of different types, ages and configuration cover about 62% area of western Rajasthan. Mobility of sand dunes causes obstacle to agricultural operations, roads and rail traffic, and other infrastructures. Developing the techniques for stabilisation of sand dunes was, therefore, taken up by CAZRI since its inception (Fig. 7).

The sand dune stabilization technique of CAZRI consists of (a) fencing of the area, (b) establishment of micro-wind breaks on the windward side of the dune in 5 m chess board pattern or in 5 m parallel strips, and (c) sowing of grasses and transplanting of trees and shrubs with the onset of monsoon. For raising micro-wind breaks, locally available brushwood materials like *Leptadenia pyrotechnica* (Khimp), *Colligonum polygonoides*, *Ziziphus nummularia* (Pala), *Crotalaria burhia* (Sania) and *Panicum turgidum* (Murath) can be used. Suitable tree species for sand dune stabilisation are: *Acacia tortilis, Prosopis* spp., *Acacia jacquemontii, A. nubica, Colophospermum mopane* and *Tecomella undulata.* Among grasses, *Lasiurus sindicus* and *Cenchrus ciliaris*, and among creepers *Citrullus colocynthis* are suitable.

The Institute stabilised a number of sand dunes through the above technique, especially in parts of Jodhpur, Bikaner, Churu, Jhunjhunun, Nagaur and Barmer districts, which became live models for training to popularise the concept. State Forest department is now using the technology in dune-covered areas of western Rajasthan, and is reported to have fixed sand dunes in about 0.4 million ha area. CAZRI also demonstrated aerial seeding technique for stabilization of sand dunes in the inaccessible parts of the western districts, which helped in pasture development and green cover.

Shelterbelt plantation

Depending on the magnitude of wind erosion hazard, erection of five-row or three-row shelterbelts with staggered planting and in pyramidal shape, has been recommended by CAZRI.

Suitable shrub species for flank rows are *Acacia bivonesa, A. ampliceps, Ziziphus mauritiana* and *Calligonum polygonoides*. For central rows the suitable tree species are *Acacia nilotica, A. tortilis, Azadirachta indica, Cassia siamea,* and *Albizia lebbeck*. The Institute erected and maintained shelterbelts in about 500 km length, which included plantation of more than 100 km length in the state-owned farm at Suratgarh. Roadside plantation for more than 200 km length on the state highways of Jodhpur, Barmer, Jaisalmer, Churu, Jhunjhunun, Nagaur, Ajmer and Pali districts, as well as more than 100 km long plantation along the railway tracks between Sikar and Loharu, Sikar and Fatehpur, and Palana and Deshnokh have been done. All these developed sites have been handed over to respective departments for maintenance and replication. To prevent IGNP canal from silting intensive plantation was performed on the advise of CAZRI, which reduced huge cleaning expenditure on exchequer.

Controlling wind erosion from croplands

For controlling wind erosion from croplands, following techniques have been found effective: (i) micro-wind breaks of castor and *Lasiurus sindicus*; (ii) strip cropping of grass with crop (6:1 ratio of crop: grass strip); (iii) leaving stubbles of pearl millet after harvesting; (iv) creation of a cloddy surface; (v) ridge-furrow cultivation; and (vi) shelterbelts of *Cassia siamea, C. mopane* and *Acacia tortilis*.

Techniques for rehabilitating rocky habitats

Techniques for plantation on rocky and shallow gravelly habitats have also been developed. *Acacia tortilis, Prosopis juliflora, Acacia senegal, Grewia tenax, Anogeisus rotundifolia* and *Euphorbia caducifolia* are some of the suitable tree species for such sites. In the rocky rangeland of Bhopalgarh, reseeding of *Cymbopogon jwarancusa* and *Cenchrus setigerus* provided good results on shallow land having less than 10 cm soil depth. *Dichanthium annulatum* and *Cenchrus ciliaris* could be established to produce higher forage on land having 10-20 cm soil.

On the request of District Rural Development Authority (DRDA), Jodhpur, CAZRI demonstrated the rehabilitation technology on rocky wasteland of Kailana. Its benefits in terms of species richness, tree-shrub density and stand vigour, as well as regeneration of endangered species have been realised.

Mine spoil rehabilitation

Rehabilitation of mine spoils through vegetative means is often hindered by the lack of resident microflora that act as both source and sink for essential plant nutrients and is fundamental to the transformation and flow of plant nutrients. A technique for rehabilitating gypsum and limestone mine spoils of Rajasthan State Mining and Mineral Development Corporation (RSMDC) was developed using arbuscular mycorrhizal fungi/*Bradyrhizobium* and employing various amendments (pond silt, sewage sludge, FYM and normal soil), coupled with water harvesting structures, which helped in improving the soil biological productivity. This enhanced the uptake of plant nutrients, besides improving the establishment and growth of tree species on these mine spoil sites. Planting *Acacia senegal, Prosopis juliflora, Tamarix aphylla* and *Cercidium floridum*, in micro-catchments with inward sloping bench terraces for water harvesting, proved promising. CAZRI has provided technological assistance to RSMDC for reclamation of their mine spoils areas, and gets requests regularly for rehabilitation of other spoiled sites.

Grassland improvement and management

Suitable varieties: Grasses are ideally suited for the desert ecosystem. CAZRI has screened a number of promising strains of desert grasses, viz., *Cenchrus ciliaris* (Anjan), *Lasiurus sindicus* (Sewan), *Cenchrus setigerus* (Dhaman), *Dichanthium annulatum* and *Panicum antidotale*, and has come out with improved varieties/strains of grasses like Marwar Anjan (CAZRI-75), 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 sindicus*, and CAZRI-347 of *Panicum antidotale*, as well as pasture legumes like CAZRI-144, CAZRI-1462 and CAZRI-1258 of *Lablab purpureus*, and CAZRI-453, CAZRI-466 and CAZRI-468 of *Clitoria ternatea.* All these improved strains have higher protein and are easily digestible by the livestock.

Management: To increase forage production from overgrazed and denuded pastures, reseeding with high-yielding varieties of perennial forage grasses like *Cenchrus ciliaris*, *Cenchrus setigerus, Lasiurus sindicus, Dichanthium annulatum, Panicum antidotale* and *Sehima nervosum* have been found most suitable. *Dichanthium annulatum* gives high yield on heavy soils with >380 mm annual rainfall, while *Cenchrus ciliaris* and *Cenchrus setigerus* produce high forage on sandy soils under medium to low rainfall. *Lasiurus sindicus* gives high yield on sandy soils under <200 mm rainfall. *Panicum antidotale* performs well under protected conditions and on medium textured soils in >250 mm rainfall, while *Sehima nervosum* yields good forage on hilly terrain. Contour furrows, contour bunds and contour trenches have been found to increase moisture conservation and forage yield. Regeneration of *L. sindicus* was much better after contour furrows were created (Fig. 8).

The overall productivity of grasslands has been increased by reseeding of genetically improved strains, and application of 20 kg ha^{-1} each of N and superphosphate. Inclusion of top feeds like *Ziziphus nummularia, Dichrostachys nutans, Colophospermum mopane, Prosopis cineraria*, etc., further add to the productivity and carrying capacity of the rangelands. Sown pastures provided better economic return with a pay-back period of 13 years.

Seed production: Technology for pelleting of quality grass seeds through an improvised machine comprising of used tractor tyre has been developed. CAZRI's Research Farm at Jodhpur and at Regional Research Stations produce quality seeds of improved grass varieties to cater to the increasing demand of the farmers, as well as of numerous government and non-government agencies. The institute has drawn up a plan to enhance the quality grass seed production further.

TREE INTRODUCTION AND IMPROVEMENT

Tree identification and selection

CAZRI has paid considerable attention to the introduction and selection of fast-growing exotic and native tree and shrub species from various iso-climatic regions of the world. *Eucalyptus camaldulensis, E. terminalis, Acacia albida, A. tortilis, A. bivenosa, A. ampliceps, A. eriopoda, Colophospermum mopane, Dichrostachys nutans, Prosopis* spp. (Peruvian), *P. alba, P. chilensis, Hardwickia binata,* and *Pongamia pinnata* have shown promises in Indian arid zone.

Plus trees of *Prosopis cineraria, Tecomella undulata, Acacia albida, A. senegal, A. nilotica* subsp *cupressiformis* and *A. tortilis* subsp *radiana* have been identified. Progeny trials and seed orchards of these species have been established. Genetic polymorphism in natural populations and mating systems has been investigated using iso-enzyme markers.

Macro- and micro-propagation of trees

Macro-propagation technique for plus trees of *Prosopis cineraria* has been developed and utilised for establishment of clonal seed orchard. Exotic *Prosopis* species have been successfully propagated through vegetative means. Air layering of *P. cineraria* has been found useful for its vegetative multiplication. Vegetative propagation techniques for multiplication of female plants of Jojoba in mist-chamber have also been standardised.

Protocols for *in-vitro* micropropagation of date-palm using apical meristem from off shoot 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 have been developed. A new technique for raising monoxenic culture of root knot nematode through tissue culture has been standardised.

Thornless *P. juliflora*

Prosopis juliflora is an aggressive thorny bush that colonises all kinds of land very fast, although it has several uses. To make it non-thorny, cleft-grafting technique was used, in which *P. juliflora* was taken as stock, and non-thorny twigs of *P. alba* and *P. pallida* were used as scion. The technique has been perfected and standardised for nursery and field conditions.

DRYLAND FARMING

Farming systems

It has been established that perennials like tree and grass systems can provide production stability under uncertain rainfall and frequent droughts of arid region. Hence, silvo-pastoral and agri-pastoral systems have been evolved for this purpose.

Agroforestry and agri-horticulture systems involving *Z. rotundifolia* + mung bean/moth bean/clusterbean and *Z. mauritiana* + mung bean/clusterbean, respectively, have been recommended in rainfall zone >300 mm and also for drought proofing. Silvopasture systems of *Z. rotundifolia* + *C. ciliaris*/*L. sindicus* have better tree/grass compatibility and have been recommended for areas having <300 mm annual rainfall.

Integrated farming systems have shown to produce fruits, fuel, fodder and timber and to sustain soil health and livestock productivity. Improved agri-horti-pasture system provides better yield of dryland crops and fruits, meets the fuel needs, and provides sustenance of 800-1000 goat/sheep days ha^{-1} $year^{-1}$.

Crop varieties developed

Following dryland crop varieties suitable for arid region have been developed and released by CAZRI:

Pearl millet:	CZP-9802 (Fig. 9); CZP-IC-923 (Composite variety)
Moth bean:	Maru Moth, CAZRI-Moth-1, CAZRI-Moth-2, CAZRI-Moth-3
Clusterbean:	Maru-Guar
Horse gram:	Maru-Kulthi-1

CAZRI has also developed pearl millet male-sterile line CZMS-44A for use in developing pearl millet hybrids for arid regions. Agro-techniques for all the varieties have been specified.

Agro-techniques

Physiological and biochemical basis of drought tolerance in pearl millet, mustard, cumin and isabgol genotypes have been studied in depth. Mild fertilization was found to alleviate the adverse effects of drought and salinity. Planting of early and late-maturing genotypes together stabilized the yield of clusterbean and moth under drought. Application of thiourea increased the yield of arid legumes, both under normal and low rainfall situations. Stems of Senna (*Cassia angustifolia*) have been found to contain plant growth promoters that improved the growth and yield of pearl millet and wheat.

Nutrient management

Maximum seed yield of mung bean, clusterbean and moth bean were obtained with the application of 20 kg nitrogen and 40 kg phosphorus ha^{-1} while in pearl millet 40 kg N + 40 kg phosphorus produced highest yield. Urea mixed with elemental sulphur reduced the volatilization losses of N and improved yield and nutrient use efficiency. Bio-inoculants (*Rhizobium* and *Azotobacter/Azospirillum*), together with organic manure (FYM/compost @ 5 t ha^{-1}), improved the yield of arid crops by 10-15%. A soil solarization technique for mass multiplication of AM fungi has been developed. Native unavailable phosphorus was mobilized by phosphatase and phytase releasing fungi (*Chaetomium globosum*, *Curvularia lunata*, *Emericella rugulosa* and *Trichoderma harzianum*) and bacteria (*Bacillus coagulans* and *Alcaligenes faecalis*). The organisms can mobilize 45-125 kg P ha^{-1} and improve the crop (clusterbean, moth bean, mung bean, pearl millet) yield by 13-28%. A potential biological indicator for arid soils has also been developed.

Management of soil crust

Soil crusting is a major problem of dryland agriculture. Application of 5-10 t FYM ha^{-1} over seed furrows, has been found to mitigate the adverse effects of soil crust on seedling and facilitate emergence of seeds. It has been demonstrated on farmlands of several villages through participatory approach and has become recommendation of the state government for wider adoption.

Weed management

Application of fluchloralin @ 0.75 kg ha^{-1} was effective for controlling weeds and it gave maximum seed yield and net returns in moth bean. Integration of fluchloralin or pendimethalin @ 0.5 kg ha^{-1}, along with one hand weeding at 30 days after sowing (DAS), is most effective in managing weeds in mung bean and mustard.

Arid horticulture

Arid horticulture with or without crops and grasses has been found to establish productivity even during drought years. Due to CAZRI's efforts, the region has now following improved varieties of fruit crops that have become popular and are readily adopted by the farmers and entrepreneurs in the arid region. It has also spread to Gujarat, Maharashtra, Madhya Pradesh, Andhra Pradesh and Karnataka.

Ber (*Ziziphus mauritiana*)**:** Improved varieties of Ber (Gola, Seb and Mundia), identified by CAZRI, have made a big impact in arid and semi-arid regions. Propagation technique of ber through budding, control of ber fruit fly, water harvesting through micro-catchments, optimum spacing (6 x 6 m), fertiliser requirement, post-harvest technology, etc., have been standardised. Inoculation of nursery soil with *Azotobacter/Azospirillum* and AM fungi has been found to provide sturdy seedlings and facilitate early budding of ber seedlings. The ber technology has been widely popularised and has earned immense goodwill for CAZRI, with products sold in the market in the name of "CAZRI ber" (Fig. 10).

Pomegranate (*Punica granatum*): Cultivar Jalor-seedless of pomegranate has been identified and its propagation technique, optimum spacing (5 x 5 m) and agro-techniques standardized Irrigation through drip system at flowering and fruiting stages considerably increased the yield and reduced fruit cracking. CAZRI has recommended for its cultivation in arid and semi-arid regions.

Bael (*Aegle marmelos* L.): High yielding cultivars of bael, viz., Dhara Road and Faizabadi Local, have been identified and propagation technique through budding have been standardised.

Aonla (*Emblica officinalis*): Some promising Aonla cultivars have been identified and their propagation technique by budding has been standardised.

Pest management

Integrated disease and pest control measures for various crops have been developed. Neem (*Azadirachta indica*) and *Calotropis* extracts have been effectively used for control of a number of pests. To control soil-borne pathogens in crops like sesame, cowpea, clusterbean and cumin soil solarization for 15 days during hot summer has been found effective. Bio-formulation prepared from a soil bacterium has provided resistance against dry root rot in clusterbean and wilt incidence in cumin. These formulations are being marketed through ATIC as Maru Sena 1 and Maru Sena 3. Dry root rot has also been controlled by the use of mustard pod residues @ 2.5 t ha^{-1} with one summer irrigation during early summer. Control measures for white grubs, termite, grasshoppers and hairy caterpillars have been developed. A laboratory technique for raising mono-xenic culture of root knot nematode through tissue culture has been standardised. Ganoderma infestation of *P. cineraria* trees has been checked and dying trees revived through effective control methods.

Effective measures for the control of major termite pest *Odontotermes brunnes* in forestry plantations, and *Microtermes tenuignathus* in wheat crop have been devised. Studies on rodent ecology have generated valuable information with respect to optimum seasons for control operation and effective ways of bait placement, as well as developed different effective bait formulations.

ARID WATERSHED MANAGEMENT

CAZRI developed an arid watershed at Jhanwar, covering an area of 1200 ha, as a model watershed. About 60 ha of community land was developed as an ideal pasture for animal grazing. Besides 6 to 7 q of grass seed year^{-1}, the previously barren land could yield 20 to 30 q ha^{-1} good quality dry forage. Improved dry farming technologies were widely adopted by the farmers. The rocky and gullied catchments were treated with mechanical and vegetative measures, which resulted in 8-fold increase in biodiversity and rise in ground water recharge at the rate of 0.70 m year^{-1} in the watershed. An additional 3240 m^3 of surface water potential was generated in the watershed by farm ponds of 271 m^3 capacity, which helped in raising agri-horticulture system. Watershed management resulted in overall resource conservation and increased crop productivity by 25-30% with sustained socio-economic development. This watershed was recognized by the United Nations Environment Programme (UNEP) for outstanding contribution in combating desertification and controlling land degradation in dryland environment.

Since then CAZRI has demonstrated improved land management practices in selected watersheds at Baorli-Bambhore, and Sar villages in Rajasthan and at Kukma in Gujarat. The khadin at Baorli-Bambhore generated an income of Rs.18500 ha^{-1} through forage production during the extreme drought year of 2002. Runoff water harvested in the farm pond at Kukma is free from fluoride and has been found to be excellent for drinking and irrigation.

LIVESTOCK MANAGEMENT

Multi-nutrient feed block

Using low-cost ingredients like animal-grade jaggery, urea, common salt, mineral mixture and wheat bran, CAZRI has prepared multi-nutrient feed blocks for animals. Feeding these blocks to cows and buffaloes increased the daily milk yield by 15-25% and rectified their reproductive problems due to mineral deficiency. Multi-nutrient feed blocks are becoming popular with farmers.

Non-conventional silage

Tumba (*Citrullus colocynthis*) seed cake, a by-product of oil industry, containing 16-22% protein, has been found to be a healthy non-conventional feed for heifer. *P. cineraria* leaves have been made more digestible by removing tannin from it through heating with 0.5 N aqueous solution of sodium bicarbonate.

Mineral mixture for sheep and goat

A mineral mixture, named 'Ibomix' was developed, which showed beneficial effects in body weight gain, milk and wool production, and early maturity in sheep and goats of the region.

Improved management

Scientifically managed Tharparkar heifers (balanced feeding and treatment of gynaecological disorders) calved at the age of 33 months under arid condition, instead of the normal 54-60 months, which improved milk production and quality of milk. The productivity and adaptability of various goat breeds like Marwari, Parbatsar, Shekhawati, Jakhrana, Kutchi, Barbari and Jamunapari, have been studied. During the worst drought of 2002 the Institute worked with the State line departments to organise more than 175 cattle training camps to enrich poor quality fodder and to demonstrate improved management practices during such crises.

PLANT AND ANIMAL BY-PRODUCTS

Gum-arabic from Kumat

Kumat (*Acacia senegal*), which grows well in rocky terrain of western Rajasthan, is a known source of industrial gum. Presently this gum is imported from Sudan. CAZRI has now developed a simple technique for increasing gum exudation (0.5-1.0 kg $tree^{-1}$) from the tree by injecting ethephon (Fig. 11). An investment of Rs. 10 per injection can easily earn Rs. 300 per tree per year. Therefore; the technique is becoming popular very fast, and tree plantation on wastelands is also getting a boost.

Anti-HIV constituents from Rohida plant

Rohida (*Tecomella undulata*) leaves have been found to contain oleanolic acid, ursolic acid and betulinic acids, compounds that are potent HIV prohibitor. Octadimethyl succeinate derivatives of oleanolic acid and betulinic acid have been reported to be 24 times more active than AZT, a drug that is currently used for checking the spread of AIDS.

Oil-yielding plants

Oil-yielding plants like Peelu (*Salvadora oleoides*) and Tumba (*Citrullus colocynthis*), which are native to the drier parts, have been identified. Potentials of Jatropha in wetter margins of arid zone are under evaluation.

Plants of medicinal and industrial values

A number of compounds of industrial value have been isolated from under-utilised and unexploited arid zone plants. These include Diosgenin, an anti-fertility agent from seeds of *Balanites aegyptiaca*, Candelilla wax from *Euphorbia antisyphilitica*, 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 Oleo-resins from *Commiphora wightii*. Institute is also working on developing a range of products from *Aloe vera*.

Value-added plant products

Recipes have been standardised for preserve of ber; squash, jam, jelly, and anardana of pomegranate; jam, preserve and shreds of aonla; and squash, preserve and jam of bael, as well as juice of Peelu fruit (*Salvadora oleoides*). These products are prepared and sold from Agricultural Technology Information Centre (ATIC) of CAZRI. The Institute has also succeeded recently in preparation of jam and candy from *Aloe vera*, as well as edible products from Tumba (*Citrullus colocynthis*).

Milk products

Milk-products like paneer, cheese, kesar kulfee (variety of ice cream) and whey drink have been prepared from goat milk. Technology has been developed for preparing a flavoured whey drink by boiling the raw whey and then sweetening it, flavoured and acidified with citric acid. Total solids, fat, protein, ash, density and water-soluble vitamins are significantly higher in goat whey than in cow whey. The processed goat milk products being odourless, have good demand in local urban market.

AGRICULTURAL ENGINEERING AND ENERGY MANAGEMENT

Tractor-operated seed-cum-fertilizer drill: A 3-furrow (6-row), tractor-operated seed-cum-fertilizer drill, with a provision for seed-pressing device, has been designed and developed for sowing pearl millet. With the use of this seed-cum-fertilizer drill the crop can be sown on slant surfaces (5 cm below) of a furrow (300 mm wide at the top and 200 mm deep) while still maintaining its shape and slope.

Ber grader: A manually operated ber grader has been designed and developed, which grades ber into three sizes of <25 mm, 25-35 mm and >35 mm dia. @ 500-600 kg ha^{-1}.

Passive cool chamber: A passive cool chamber, having double wall system, has been designed and developed on the principle of evaporative cooling for storing vegetables, fruits and milk for a longer shelf life.

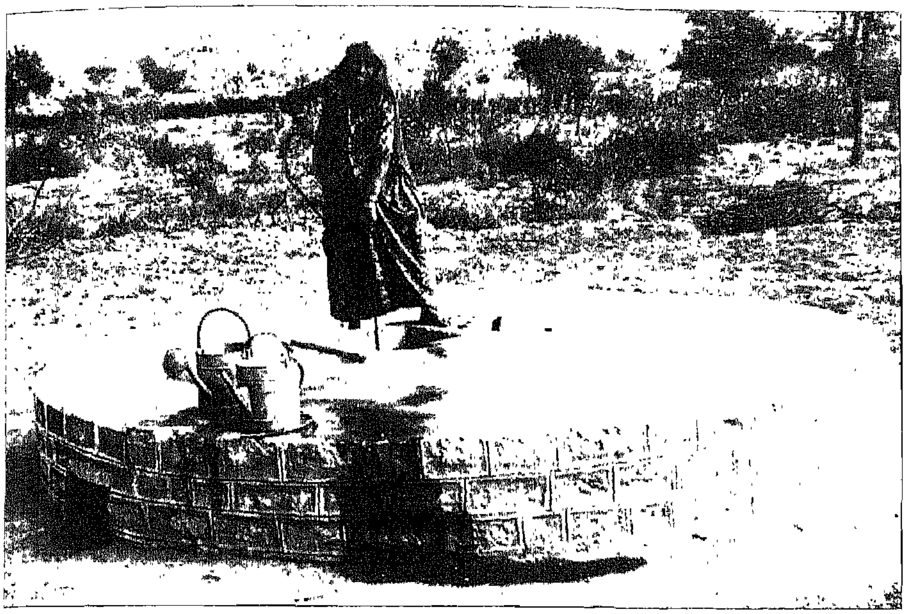

Fig. 6. Improved Tanka in a village.

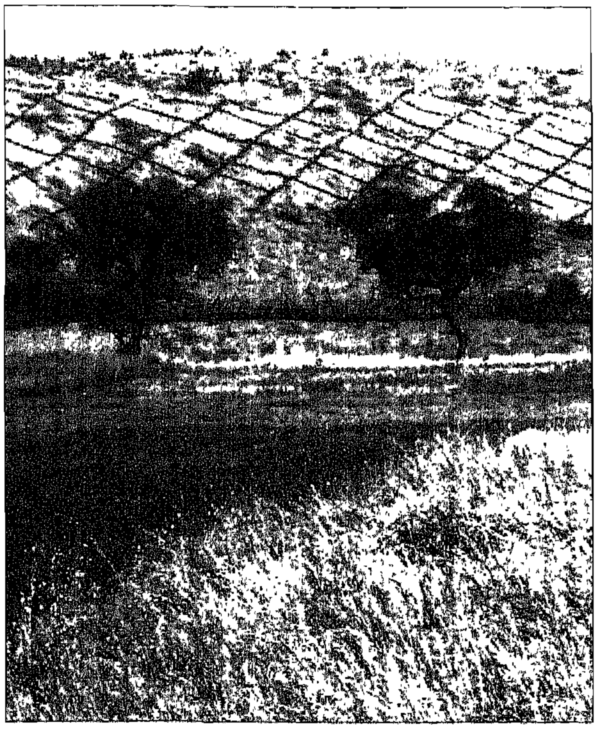

Fig. 7. Stabilization of a sand dune using vegetative method in progress.

Fig. 8. Improved *Lasiurus sindicus* grass for low rainfall regions.

Fig. 9. Pearl millet variety CZP-9802 for cultivation in drought-prone areas

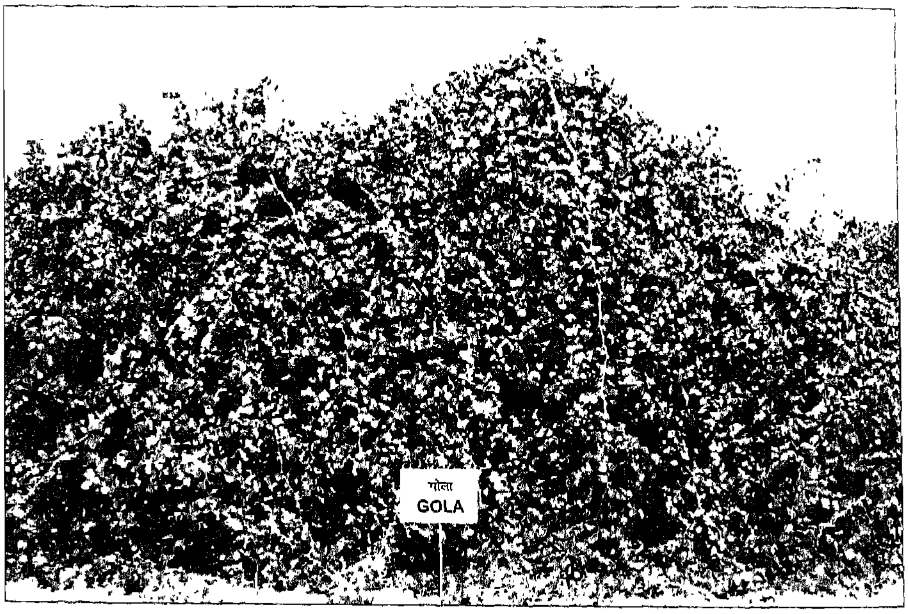

Fig. 10. Gregarious fruiting of improved Gola variety of CAZRI Ber.

Fig. 11. Gum exudation from *Acacia senegal* tree after ethephon injection.

Solar appliances: The solar appliances developed by the Institute for adoption in rural and urban areas include: 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, and solar candle making machine, poly-houses, etc. Some of these are used by small entrepreneurs and individual farmers. Solar candle making machine has been transferred to NRDC, New Delhi, for commercialisation. Solar dryers of various capacities have been developed and tested for drying fruits and vegetables.

A solar cooker for animal feed has been designed and developed to boil 10 kg of animal feed per day, sufficient for about 5 cattle. The cooker is made up of locally available materials e.g. clay, pearl millet husk and horse excreta/cow dung. A lightweight, shoulder-mounted solar PV duster with storage facility has been developed for dusting insecticide powder. A solar PV pump-operated drip irrigation system has also been developed. Development of an electronic solar tracker now helps the small fixed solar devices to always turn to the sun from sunrise to sunset, and thus get maximum energy.

SOCIO-ECONOMIC EVALUATION AND EXTENSION ACTIVITIES

Problems of nomads

The lifestyle and problems of the neglected nomads viz., Gadoliya Lohars and Raikas, and of the semi-nomadic people have been studied for understanding their needs and aspirations under the fast changing scenarios of the desert. Symbiotic relationship between the settled non-pastoralists and the pastoral nomads is crumbling because the nomads are no longer welcomed by the settled population. During the IGNP Phase-I construction, CAZRI prepared the rehabilitation plan for settling the Gadoliya Lohars of Anupgarh area. Institute has also studied the problems of scheduled tribe populations in the desert.

Pastoral communities in modern times

Studies on Raikas and Sindhi Muslims of the desert revealed that more than half of these sheep and goat raisers practiced long-distance migration. Those who did not own livestock practiced cropping with meagre land holdings. Joint families and large families with nine or more members performed more migration than the nuclear and small families. Majority of sample pastoralists (~93%) perceived that grazing resources have been deteriorated due to poor rainfall and felling trees on grazing lands, but few (~7%) perceived excessive grazing as the cause of degradation.

Adoption of improved farm practices

The innovativeness of farmers depended on the availability of inputs like irrigation, fertilizers and plant protection, etc., while risk-bearing capacity of farmers was related to security measures like crop insurance. In Sikar district, small and marginal farmers adopted more of the improved practices through inter-personal communication, only when the better input (drip irrigation facility) was available, and crop insurance secured the farmers.

Economics of sheep rearing

Western Rajasthan is a major area for sheep rearing. No perceptible relationship was found between flock size and holding size, even though sheep rearing is not independent of land holding. The size of the flock is determined more by mortality rate than by market force or resource rationale.

Economics of technologies

Cost-benefit analyses show that various techniques like, pasture-based livestock management, afforestation using fuel/fodder tree species, agro-horticulture, agri-pasture, sand dune stabilisation, shelterbelts, etc., are cost-effective. The internal rate of return of these technologies favourably compares with the long-term rates of return on borrowing from banks. The only constraint is the long gestation period associated with these technologies.

Economics of naturally growing shrubs in the desert

Some of the xerophytic shrubs, which grow naturally in arid areas, have significant economic potential. Comparison of net annual benefit:cost ratio provide economic justification for growing *C. colocynthis* (1.03:1) for oil, *T. undulata* (0.35:1) and *P. cineraria* (0.46:1) for timber, as well as *Commiphora wightii* (0.18:1) and *A. senegal* (0.13:1) for gum and resin.

Women in agriculture

Women's contribution to agriculture has been found to be substantial, particularly in livestock-based activities (60-90%). Unfortunately, their access to income is negligible. Use of drudgery-inducing tools and lack of empowerment and training are the major constraints in the upliftment of their condition. Therefore, some focused programmes to develop user-friendly tools, and training of women in livestock-based activities, agricultural operation, product processing for income generation, health and hygiene, etc., are regularly carried out by the Institute.

Transfer of technology through education and training

The Institute has conducted numerous national and international training courses over the years. Apart from providing regular training through Summer Institutes, Winter Schools, and other need-based trainings to ICAR institutes, SAUs, and state departments, it has also conducted specialized international training courses, especially for UNESCO, ESCAP, FAO/DANIDA, US-AID, etc.

The Extension wing of the Institute and the Krishi Vigyan Kendras (KVKs) at Jodhpur and Pali play important roles in imparting training to farmers, rural women, unemployed youth, etc. About 2500 farmers' training courses involving more than 40000 farmers have been conducted during the last two decades. Numerous training courses have also been organised for the extension personnel of state agencies and non-government organisations. Moreover, the Institute organises regular Kishan Melas (farmers' fares) and demonstration camps in villages, as well as in its premises, which attract a large number of villagers.

More than 150 villages in western Rajasthan have been reached directly by CAZRI for on-farm demonstration of technologies related to arid land management through various programmes. Additionally, training and advisory services have been provided to farmers from a very large number of villages in arid Rajasthan, Gujarat, Haryana and Punjab, as well as from other parts of the country. An Agricultural Technology Information Centre (ATIC) caters to the needs of the farming community and others interested in the technologies and produce of CAZRI.

SUMMARY OF TECHNOLOGIES AVAILABLE FOR TRANSFER

The five decades of research at CAZRI has yielded a number of technologies that are continuously upgraded or are replaced with new ones. Details of technologies that are presently available for immediate dissemination and adoption for tangible gains in food productivity are given below (Table 5).

Table 5. Technologies available for transfer, with average benefit-cost ratio and payback period

Name of technology	Cost	Crop/farming system for which suited	Water use efficiency (WUE)/ water conserved	Increase in agricultural yield and other benefits in livestock, etc.	B:C ratio	Pay back period
Improved water harvesting structures	Variable; approx. Rs. 40000-50000 per farm pond	Drinking/horti-based farming system	Rain water conservation & utilization	80 to 120%	1.75 to 2.50	IInd year
Management of land irrigated with sodic water	Variable; approx. cost 4000-10000 ha^{-1}	Sodic soils and brackish water irrigated area	High WUE	200 to 500%	2.5 to 4.5	Ist year
Improved cultivation of ber and other horticultural crops	Approx. Rs. 10000-15000 ha^{-1} for 3 years as establish-ment cost	Dryland/ irrigated farming systems	WUE by 40-50%	200 to 350%	2.5 to 3.5	IVth year
Increased gum production from *Acacia Senegal* tree	Rs. 40/tree	*A. senegal*-based farming system	Yes	400 to 750 g gum $tree^{-1}$	2.0 to 3.0	Ist year
Farming systems and diversified agriculture	Variable	Rainfed/irrigated farming system	Yes	100 to 400%	Variable, both tangible & non-tangible	Ist year to IV year
Arid watershed management	Depending on watershed development programme approx. Rs. 4000-6000 ha^{-1}	Multiple water use in rainfed and irrigated farming systems, integrated land management	Yes	250 to 500%	1.0 to 4.0, variable	IInd year
Pressurised irrigation	Rs. 30,000 for sprinkler and Rs. 65000 for drip	Almost for all crops, tomato, chilli, cotton, vegetables, melons, and for horticultural crops	30-55% saving of water	35-50% increase in yield over check-basin and furrow irrigation methods	-	2-4 years depend-ing upon the type of crop and irrigation system
Cropping systems for rainfed and irrigated farming	Variable; Rs.3000-5000 ha^{-1} for rainfed, depending	Arable cropping systems	150-200%	200 to 400%	1.4 to 2.5	Ist Year

	on system; Rs.7000-10000 for irrigated					
Develop-ment of crop varieties: Pearl millet variety CZ1C 923 (released and notified 1996)	Rs.150 ha^{-1} (seed cost)	Crop based farming system	Suitable for both irrigated and rainfed	7-20% more grain yield	-	Same year
Develop-ment of crop varieties: Pearl millet variety CZP9802 (released & notified 2002)	Rs. 150 ha^{-1} (seed cost)	Crop based farming systems	Variety is suitable for extremely arid districts having annual rainfall of less than 400 mm.	14% higher grain yield	-	Same year
Develop-ment of crop varieties: CAZRI Moth-1	Rs.5000-6000 ha^{-1}	Sole cropping, intercropping with pearl millet	-	10-15% higher, resistant to YMV, higher fodder (2500-3000 kg), grain protein 25%	2:1	Same year
Develop-ment of crop varieties: CAZRI Moth-2	Rs. 5000-6000 ha^{-1}	Sole cropping, intercropping with pearlmillet, late planting up to July end	-	15-20% over CAZRI Moth-1, grain protein 25%	2:1	Same year
Develop-ment of crop varieties: CAZRI Moth-3	Rs. 5000-6000 ha^{-1}	Dry zone, poor soils, sole cropping, inter-cropping with pearl millet	-	10-12% higher, drought-hardy, escapes YMV	3.5:1	Same year
Grass: CAZRI 75 (Marwar Anjan)	Seed cost Rs. 1000; total cost approx. Rs. 4000 ha^{-1}	*Cenchrus ciliaris* pasture establishment, suitable for sowing in kharif season	Drought-hardy	Depending on rainfall, about 50% more green fodder and 30% more dry fodder	-	IInd year
Grass: CAZRI 76 (Marwar Dhaman) - 1985	Seed cost Rs 1000; total cost approx. Rs. 4000 ha^{-1}	*Cenchrus setigerus*	Drought-hardy	10-20% higher green fodder	-	IInd year onward
Grass: CAZRI 2221 (Genetic stock) - 2003	Seed cost Rs. 1000 ha^{-1}	*Cenchrus ciliaris* pasture establishment	Drought hardy	About 20% more green fodder	-	IInd year onward
Multi-nutrient feed	Rs.10-12 kg^{-1}	Large and small animals in	-	18-40% increased	3.0	1.5

block		rainfed farming system		milk production		months
Complete feed block	Rs. 5-6 kg^{-1}	Large and small animals in rainfed farming system	-	15% increased milk yield in large animals	2.1	1.5 months
Multi-nutrient mixture	Rs. 8-10 kg^{-1}	Large and small animals in rainfed farming system	-	40% increased milk yield in small animals	3.4	1.5 months
Urea treatment of straw	Rs. 0.40-0.45/ kg^{-1}	Large and small animals in rainfed farming system	-	20% increase in yield	4.02	2 months
Kulfi making from goat milk	Rs.15 kg^{-1}	Small animals in farming systems	-	100% increase in income	2.0	10 days
Paneer and whey from goat milk	Rs.10 kg^{-1}	Large and small animals in rainfed farming system	-	60% increase in income	2.0	15 days
Rodenticidal baits for rodent management	Rs. 15-30 kg^{-1} bait (sufficient for 50-75 rodent burrows)	Rainfed and irrigated areas in arid zone	Not applicable	About 80% success in rodent control	10:1	5-10 days
IPM: Maru sena -2	Seed treatment Rs.25, soil application Rs.100	Cumin	N.A.	0.5 q ha^{-1}, depending on wilt	1:70	4 months
IPM: Maru sena-1	Seed treatment Rs.25, soil application Rs.100	All crops	-	0.5 q ha^{-1}, depending on disease	1:70	4 months
IPM: Maru sena-3	Seed treatment Rs.25	Legumes	N.A.	0.35 q ha^{-1}	1:25	4 months
Solar Candle Making System (Technology assigned to NRDC, New Delhi)	Rs. 12000 including moulds and solar wax melter (absorbing area 0.5 m^2)	Any where in India, particularly arid zone	About 5% saving in wax that occurs due to evaporation in conventional method	During summer:10-16 kg/day During winter: 6-9 kg day^{-1}	Supplement monthly income/unit: Rs. 2000/-	1 year
Solar Dryer	Rs. 3500 (for 10 kg per batch capacity) Rs. 35000	Fruits and vegetables	10-15% saving in loss from sun drying	Drying time reduced by >50% than open sun drying	Rs. 5.5 (for 200 kg/day capacity unit)	2 years

	(for 100 kg per batch capacity)					
Passive Cool Chamber	Rs. 3500 (for 60 kg per batch capacity, size 170x170x90 cm)	Arid region	Shelf life of fruits and vegetables can be enhanced by 3-7 days Summer: 3-5 days against 1-2 days in room Winter: 3-7 days against 2-3 days in room	20-60 kg/batch	(i) For tomato Rs.3500 year/ unit (ii) For Brinjal Rs.1500 year /unit	1 year for tomato, 2.4 years for brinjal
Animal Feed Solar Cooker	Rs. 2500 per unit	Boiling of animal feed	Saves 6750 MJ of fuel equivalent per year	Saves conventional fuel, environment friendly, saves time and reduces respiratory diseases in women	For dairy farmers	1.5 to 3.0 years
Non-tracking solar cooker	Rs.2000 per unit	Domestic cooking	Saves 1293.75 MJ of fuel equivalent per year	Saves conventional fuel, environment friendly, saves time and reduces respiratory diseases in women	For rice eaters	2 to 4 years

5. IMPACT ASSESSMENT

MAJOR TECHNOLOGIES

CAZRI, originally conceived and established as a Desert Afforestation Research Station, has attained the distinction of a unique Institute in South Asia by carrying out basic, applied and strategic interdisciplinary researches related to sustainable arid land management, including pioneering studies on sand dune stabilization, afforestation and pasture management. Over the last five decades CAZRI has evolved a large number of viable technologies to address a range of issues from environment to cropping and livestock management in the arid region. These technologies have spread far and wide and are adopted in the drylands of the country through various Central/State Government schemes, as well as through farmers' and other stakeholders' participation. A number of technologies have become major contributors to generation of rural livelihoods. Visible impacts of some of the salient technologies are described below.

Environment improvement

- CAZRI technologies have played a major role in improving the environment of arid zone. The dust/ sand storms have been reduced from about 17 in 1966 to 2.5 in 2000 with a fall of wind speed from 11 to 4 km h^{-1}. The dust load has also been reduced. This is partly a result of the land rehabilitation technologies developed, refined and spread in a participatory mode by CAZRI with the Government of Rajasthan, especially for sand dune stabilization (about 0.4 million ha) and shelterbelt plantation (about 800 km length), although natural factors and the Indira Gandhi Nahar Paryojana also played some role in establishing and maintaining a green cover through double cropping.
- Grasses are not only vital as fodder, but also as vegetal cover for binding and arresting sand movement. Lack of quality seed in sufficient quantities was a limitation that has been addressed by CAZRI. The quality grass seeds produced by the institute have now a major clientele in the Forest Department of Govt. of Rajasthan. Farmers also demand CAZRI's grass seeds for improving the nutritional status of their livestock. Involvement of the Institute in pasture development and afforestation programme goes back to the mid-1950s when it started developing 52 experimental areas spread over a rainfall zone of 150-600 mm per annum for quality grass production and development of grassland management models through rotational/controlled grazing. Once developed and demonstrated to stakeholders, most of these areas have been handed over to the Government of Rajasthan. Based on the technology, the state agencies have established 0.35 million ha pastureland in the desert with improved varieties of grasses and shrubs identified by the Institute. Had the grazing management models developed and demonstrated by the Institute been followed by village panchayats also in subsequent decades, the benefits to the livestock and overall improvement of environment would have increased manifold.
- CAZRI is a nodal Institute for coordinating the work on watersheds, agro-forestry and soil conservation, which has been recognised by UNEP.
- CAZRI is internationally recognized for its contribution in the fields of assessment, monitoring and combating of desertification. The institute is a major contributor to desertification status

mapping and monitoring, which is being furthered under TPN-1 of UNCCD activities in India. Under TPN-2 of UNCCD, CAZRI is the nodal Institute for coordinating the work on agroforestry and soil conservation for combating desertification in arid, semi-arid and dry sub-humid regions. Overall impact of combating desertification has been reflected in reduction of wind erosion and movement of sand dunes, as well as in poverty alleviation.

Horticulture revolution

- CAZRI has not only changed the scenario of arid horticulture by producing 'Seb' and 'Gola' varieties of ber, but has also helped in spreading it to the semi-arid regions down to peninsular India. At present ber orchards are seen in almost all the dryland states of the country. The average annual income of the institute from ber fruits is about Rs 0.2 million. Ber, being as effective as apple health-wise, is also providing nutritional security to the rural masses.
- Around Jodhpur the ber revolution augured in significant change in the rural and peri-urban livelihood scenario with mushrooming of nurseries based on CAZRI's planting material. There were once about 60 ber nurseries around Jodhpur, annually selling about 6 million budded plants across the country. Rural youths were employed for pruning and budding operations, generating additional employment. With time these budded plants have helped to develop nurseries in many other states. Since 1979, the nurseries supplied more than 5.5 million plants (turnover of about Rs. 25 million) and generated 36 million man-days' employment annually.
- Interest has also been shown in ber technology of CAZRI by the Sahelian countries in Africa (e.g., Niger), and the Levant countries (e.g., Israel), where the technology can be implemented.
- CAZRI has also introduced aonla, karonda and bael in arid environment with limited irrigation. Aonla is becoming popular on desert margins and in semi-arid areas. Soft seeded cultivars of pomegranate (Jalor seedless) are popular in Gujarat, Maharashtra and Karnataka.

Rural livelihood development

- Spread of budding and grafting technologies of ber in rural India, as well as that of IPM schedule for controlling fruit fly and other related technologies, imparted through on-farm and on-station trainings to farm youth is not only securing livelihood to the rural youth near home, but also ensuring due recognition for the expertise.
- Various state and private nurseries have also adopted techniques developed by CAZRI for raising fruit plants and forest trees. These are providing much needed livelihood and also producing good quality planting materials.

Water management

- The courses of the buried 'Saraswati River', which were identified by the Institute and subsequently reconfirmed by ISRO, have helped in locating groundwater that provides potable water in the dune-infested remote areas of Jaisalmer district and adjacent areas.
- CAZRI has pioneered the design of improved tanka (cistern) to livestock and store rainwater for drinking purpose, which was readily adopted by the Rajiv Gandhi National Drinking Water Mission. About 0.13 million persons per year were benefited by 12,000 tankas constructed. Another fruitful offshoot is adoption of the design by a number of farmers who use the harvested rain water for nurseries and for horticultural and fodder trees.

- Based on the technology developed by CAZRI, a subsidy programme on gypsum application for reclamation of soils affected by irrigation with high-RSC water has been taken up by the Govt. of Rajasthan.
- Initial research on sprinkler and drip irrigation at the Institute standardised the system requirements for arid sandy tracts, which has helped to bring large areas under pressurized irrigation. About 50,000 sprinkler sets are now in operation in the region, making extensive cropping possible with limited water. Currently emphasis is being given on drip irrigation and fertigation of crops.

Watershed and wasteland development

- Under the Desert Development Programme (DDP) the recommended CAZRI technologies have been readily adopted by the state, focusing on land development and soil conservation (2.74 million ha), afforestation and pasture development (1.64 million ha) and water resource development (0.90 million ha). CAZRI is an active participant in the integrated arid watershed development (86 thousand ha) with a focus on water harvesting (39 thousand ha).
- Technologies have been generated on rehabilitation of mined wastes. Rajasthan State Mining and Mineral Development Corporation has adopted the technologies developed by the Institute for rehabilitation of limestone, gypsum and lignite mined areas.

Seed and seedling production

- Supply of 5.4 tonnes seed of clusterbean variety Maru Guar and 2.3 tonnes seed of moth bean variety Maru Moth, ~1 million saplings of forest trees and >20 tonnes of grass seeds during the last two decades demonstrate the demand of the improved planting materials developed by the Institute.
- Pearl millet varieties CZP 9802 and CZP 923, developed by CAZRI, are getting popular among the farmers and are likely to spread in large areas after these have been recommended by state.
- Inspired by CAZRI's findings on the beneficial role of some bio-inoculants (*Rhizobium, Azospirillum* and *Azotobacter*), Rajasthan state and private agencies are selling about 0.15 million packets of these bio-inoculants per year.

Plant protection

- The rodent control technology developed by CAZRI has not only benefited the farmers, but also the organisations like the Railways, Airlines and Telecom departments. An indirect contribution is the retention of green cover by arresting the mortality of trees/shrubs caused by preying rodents on roots.
- CAZRI's bio-control agents of soil-borne plant pathogens, namely *Trichoderma* and *Bacillus firmus*, termed as Maru sena 1 and 3, are among the best sellers through ATIC, fetching a revenue of more than Rs. 15,000 annually.

Milk production

- Increasing the lactation period of livestock by feeding nutritive mixes and feed blocks developed by the Institute from indigenous plant(s) is increasing the milk production in the region without affecting the animal health. Demonstration of the technology at many cattle camps during the century's worst drought in 2002, helped the livestock raisers in not only saving their animals from diseases, but also in producing higher quantity of milk for market, when no crop could be sown. At present the technology of mineral mixture and feed block making is being commercialised by individual farmers and private agencies.

Gum gardens

- The simple and cheap ethephon injection technology has revolutionized the gum production from local *Acacia senegal* plants. At present the technology has been adopted in over 500 ha area with an annual estimated production of 2.5 tonnes good quality gum. The sale price is Rs. 300-500 kg^{-1} of gum. Considering the almost no cost of maintenance and very high returns, the technology is spreading fast, especially because the gum has a huge potential in the world market and can compete quality-wise with that from Africa. Other gum-yielding plant species are also being tested.

Training programmes on value addition

- Training programmes on value addition to indigenous plants and livestock products through CAZRI's technologies are very popular among the rural women.
- Training programme on raising mushroom using local plant waste material is also very popular among the rural women.
- In value addition and post-harvest processing of farm produces, preparation of squash, jams, pickles and candies of arid fruits like ber, pomegranate, bael, aonla, kair, etc., are being popularised among farmwomen for generation of additional income. Training courses are regularly conducted on these aspects for economic empowerment of women.

Solar energy utilization

- The patented design of solar candle making machine has received significant attention among the users and industry.
- Solar driers, solar dusters, solar food and feed cookers, passive coolers to store perishable agricultural produce, and other PV-based equipments are gradually becoming popular.

Besides the above, there are several other technologies in the pipeline. Establishment of seed orchards for production of genetically superior seeds of trees, resource assessment and monitoring using modern techniques, integrated pest management, ITK of cow milk as remedy for chilli leaf curl, date palm cultivation, value addition of a large number of locally available useful plant products, and development of low-cost and drudgery-reducing simple hand tools/hoes for agricultural operations are some of the small but important interventions that may make dryland agriculture more sustainable and profitable.

INPUT/OUTPUT ASSESSMENT

The CAZRI technologies are mostly aimed at the arid region of western Rajasthan covering the districts of Barmer, Bikaner, Churu, Hanumangarh, Ganganagar, Jaisalmer, Jalor, Jhunjhunun, Jodhpur, Nagaur, Pali, and Sikar. The region being highly vulnerable to drought, agricultural technologies perform very slowly and unpredictably. Even then the average rainwater use efficiency (RUE) has increased with time due to the impact of the water and crop management strategies provided by the Institute. Green cover has also increased over the decades, and so has the production from rainfed croplands.

Even though the expenditure on CAZRI has increased with time, the amount spent on CAZRI per rural person in western Rajasthan has changed only marginally (1961 price base). The benefit to cost (expenditure on CAZRI) ratio shows a sharp rise followed by a gradual fall during Vth to VIIth Plan and then again a rise during the VIIIth and the IXth Plan. The decline during Xth plan period was largest due to 3 drought years, including the century-scale drought of 2002 (Table 6). The gross returns from pearl millet, sorghum, maize, kharif pulses like mung bean, moth bean and cowpea, as well as from chickpea, sesame, groundnut, castor, rapeseed mustard, chilli, clusterbean and cotton were considered in calculation (1961 price base), but tangible benefits of sand dune stabilization, soil conservation, water conservation and management, etc., accrued over time, were not included.

Table 6. Expenditure on CAZRI per rural person in western Rajasthan, as viewed against the region's aridity index, RUE, and B:C ratio from the IInd to Xth Plan period

Plan period	Aridity index (%)	RUE (kg ha^{-1} cm^{-1})	Rs spent on CAZRI per rural person	Benefit-cost ratio
II	NA	NA	1.32	NA
III	-83	0.47	0.54	897
IV	-83	0.66	0.34	1631
V	-75	0.62	0.80	721
VI	-81	0.77	1.22	491
VII	-84	0.95	1.43	414
VIII	-78	0.91	1.49	585
IX	-80	0.60	1.50	591
X	-86	2.51	1.96	277[1]

[1]Calculation is for four out of the five-year period, three of which were severely drought-affected (including the century-scale drought of 2002).

Shelterbelts have been developed against wind erosion for resource conservation. Decomposition analysis reveals that in the sheleterd farmlands rise in net profit and employment generation is manily due to the shelterbelts than due to higher input supply (Table 7). Thus the technology developed for natural resource sustenance is also helpful in providing overall stability to the farmer's economy and improving the rural livelihood. For maximising the use efficiency of inputs, the clientele needs sensitisation to technology. This is true for both kharif and rabi crop areas in western Rajasthan.

Table 7. Impact of shelterbelt technology and input supply on net profit and employment generation

Item	Observed change (%)	Change with shelterbelt (%)	Change with input supply (%)
Net profit	435.0	399.4	31.4
Employment generation	116.5	76.5	29.9

When the impact of shelterbelt on employment generation from individual crop cultivation was analysed, again the superiority of shelterbelt plantation over other input supplies was revealed (Table 8), the higher benefit being from the cash crops grown during kharif season (clusterbean and moth bean) than during the rabi season (mustard and cumin). Even the relatively high returns from pearl millet in the sheltered fields was because the crop was grown after the application of *Citrullus colocynthis* (Tumba) cake to the field, a technology that was developed and propagated by CAZRI.

Thus CAZRI technologies not only generated more production, but also provided additional livelihood at location.

Table 8. Impact of shelterbelt and input supply on cropwise employment generation

Item	Observed change in employment generation (%)	Change in employment with shelterbelt (%)	Change in employment with input supply (%)
Kharif crops			
Pearl millet	36.1	33.5	2.3
Moth bean	57.4	42.0	13.6
Clusterbean	47.6	25.2	9.3
Rabi crops			
Mustard	36.4	23.9	12.8
Cumin	30.8	26.7	4.0

The benefit-cost ratio, net present worth (NPW) and annuity value of different technologies applied to farmers' fields, namely pasture-based systems (forage production, forage and seed production, grazing of sheep, goat and cattle on developed pasture), horti-pasture and arable farming systems, were worked out, which showed positive NPW. The highest NPW was observed in horti-pastoral system, followed by clusterbean cultivation, and pasture with cattle grazing system (Fig. 12). The internal rate of return on adopting these technologies is favourably comparable with the long-term rates of return on borrowing from financial institutions. The only constraint is the longer gestation period associated with these agriculture-based technologies in arid zone.

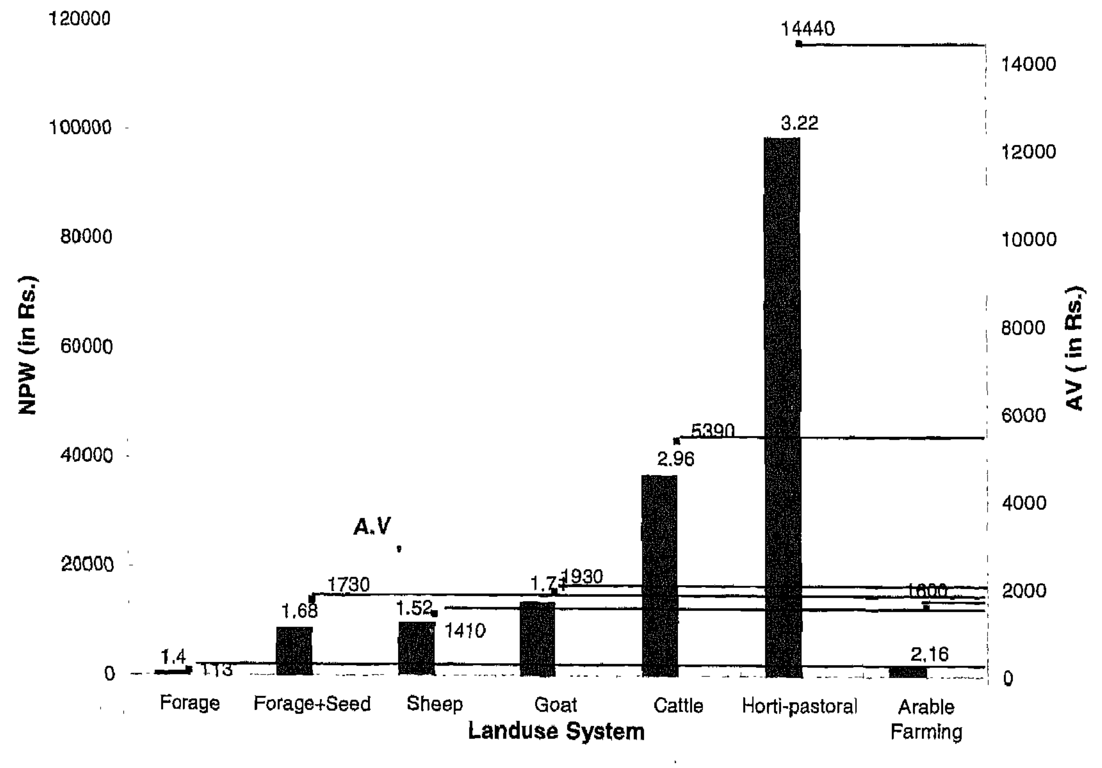

Fig. 12. Economic evaluation of long-term land management. Benefit-cost ratio is at the top of the bar; vertical lines indicate annuity values in rupees.

In addition to the tangible monetary benefits, the input can also be evaluated in terms of intangible benefits. For example, stabilization of sand dunes is an expensive proposition, but once accomplished, it minimizes the creeping of dunes on adjoining cultivated interdune plains, reduces the expenditure on sand clearance from transportation routes and vital infrastructures, and provides comfort to people by improving the local environment. Similarly the shelterbelts, the wind breaks and the roadside plantations are helping to increase crop production and minimize the wind erosion problems.

Another good example of intangible benefit is rainwater harvesting structures, which are ensuring the harvesting and storage of safe drinking water for the villages across the desert, and thus helping very survival of humanity and the livestock.

The voluntary organizations/non-government organizations, private sector and the rural mass should be motivated for popularisation of the technologies and their sustenance. There is also a need to fine-tune the on-farm research for synthesis into appropriate technology packages in a farming system perspective.

LESSONS LEARNT, SUGGESTIONS AND OPTIONS FOR FUTURE

Linking science with people: Researchers have so far been concentrating on achieving academic excellence. These efforts did find utility in both understanding desertification processes and strategies for its control management. However, for direct application of research results, people's perceptions are also to be given adequate emphasis.

Disaster resilience community: In spite of the inhospitable climate, people have survived in the desert. They have evolved and practiced a host of traditional mechanisms to cope with the adversaries prevalent in the region. There is a need to further strengthen the effort to collect, catalogue and verify the ITK existing in the region. Improved versions of these technologies may receive faster adoption and quick results.

Improvement of indigenous plants and animals: There is a strong need for greater emphasis on improvement of indigenous plants and shrubs, since the indigenous plants are well adapted to the region, pose no threat to the ecosystem and their adoption by people is feasible. Systematic natural resource surveys have generated useful information on all aspects of the region. However, little emphasis has been placed on collection and conservation of the biodiversity. The immense plant and animal wealth of arid region has many species of economic value that are now endangered and need to be conserved.

Community rangelands: If the wants, rights and privileges of the people are pressing, rather give the whole right and income from the community rangelands (*orans*, etc.) to the village community body (panchayat) than abandon the rangeland itself to forces of destruction. This should be the motive.

Livestock: The farming system in the Indian arid zone is largely based on livestock. Hence focussed research efforts are required on livestock-based farming systems. The region has some of the best breeds of animals that are well adapted to the arid conditions, and are more efficient than the exogenic breeds that are being introduced with time, especially in the irrigated areas, resulting in mixing of breeds. Unfortunately, the full potentials of the local breeds are yet to be documented and exploited under a science-mediated livestock-based farming system under modern perspectives.

Without a concerted and focussed research effort the full potential of the local breeds cannot be realized.

Sensitisation for water budgeting: Judicious use of limited water is the key for successful agriculture in arid region. Excessive use of groundwater has almost exhausted the reserve in large areas, while the excessive use of canal water in the IGNP command areas is leading to water logging and secondary salinization. This calls for a better understanding and monitoring of the water budgets, as well as development of viable technologies for groundwater augmentation and higher water-use efficiency through multiple uses of water. The traditional rainwater harvesting and storage structures need to be revived and water ponds may be desilted to increase storage capacity and efforts made to prevent mining and disturbance of the catchments.

Pest scenario: Pests, including rodents, have unique ways for survival in the desert. These pests proliferate rapidly during favourable conditions, resulting in epidemics. Importance of their control was realized long ago, but the complexity of the region and fluctuations in disease pattern due to variations in microclimate due to irrigation have made the task difficult. Hence increased effort on integrated pest control is warranted, especially through organic-based pesticides.

Land use: Multiple use of land may not only generate employment to rural folk, but also help in income generation and keeping the land covered with green biomass that may go a long way in minimizing the soil erosion. This may warrant adopting alternate landuse systems like agroforestry, silvopasture, horti-pasture, etc. But caution is needed to match the extent of biomass cover with the soil moisture available.

Mechanization of tillage: Tractors were introduced in arid and semi-arid regions in late seventies and have virtually replaced draught animals on farmlands. Situation is not likely to revert back now and tractors will remain an integral part of desert farming. Tractors have harmed the environment in two ways: (a) increasing soil erosion, leading to loss of fertile topsoil and compaction of the sub-soil, and (b) preventing regeneration of new saplings of important trees and shrubs like *P. cineraria*. In view of this, measures need to be taken to counter the adverse effects of tractorization, and create shelterbelts to minimize soil erosion.

Planning for market needs: In our over-enthusiasm we may switch over from conventional arid arable crops to industrial crops. But before that there is an urgent need to develop strong market intelligence. As soon as a cheaper row material is available, industrialists may abandon such high value crops leading to market crash. Senna is an excellent example where price of leaves came down from Rs. 35 a kg to less than Rs. 10 a kg within a span of 3 years. More caution needs to be taken for perennial crops since gestation period for economic returns is longer.

Blending scientific knowledge with local knowledge: On-farm research and fine-tuning of technologies at the farmers' fields, particularly for small and marginal farmers, need further emphasis. It has now been realized that a technology, irrespective of its merits, cannot be successful without people's active participation.

Technology transfer: Arid zone by and large being single crop area, farmers have limited period of engagement in agricultural activities in this region. There is need for developing viable activities/processes that may help in generating additional income during their spare time for improving their livelihood.

Capacity building and linkages: Linkages with national and international organizations, government organisations, line departments and voluntary organizations need further strengthening. Being a public research institute, it will be necessary to undertake long-term basic, strategic and anticipatory researches. In-built mechanism is also needed for coordination of the research system focusing on greater credibility and accountability. The organizational structure and infrastructure need to be improved upon to take full benefit of modern research methodologies through information technology, and for developing a system for enhancing research efficiency. Human resource development is a priority area for modern research and needs to be strengthened. All out efforts are required to evolve strategies to address the issues related to alternate land use systems and integrated farming systems, involving livestock, arable and perennial crops, and demonstrate these to stakeholders for wider acceptability.

In view of the variability in rainfall taking place in the assured semi-arid zones of the country, there is a possibility that such areas would gradually be under the grips of desertification, and would need the interventions of CAZRI for solving their problems. Additionally, the coastal deserts and the cold deserts may also seek technology assistance from CAZRI, for which a networking of Institutes will be helpful.

6. SCENARIO: PRESENT AND FUTURE

The hot arid zone in India occupies 0.32 million km^2 area (Fig. 13), which is located in parts of Rajasthan (61.9% of the country's total hot arid zone), Gujarat (19.6%), Punjab and Haryana (8.6%), as well as Andhra Pradesh, Karnataka and Maharashtra (9.9%).

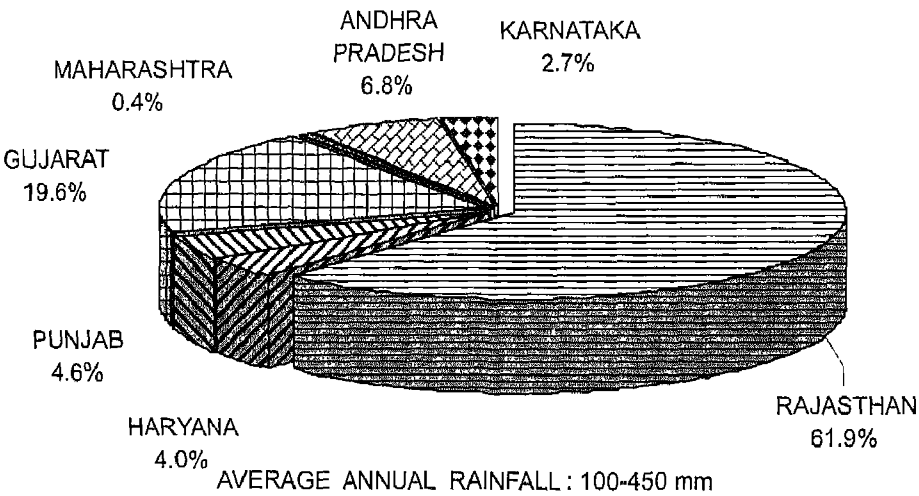

Fig. 13. Statewise distribution of hot arid zone in India.

Agrarian economy of the arid zone, especially in western Rajasthan, is at the doorstep of major changes. As the technology-mediated packages of Green Revolution and democracy-mediated infrastructural developments have percolated into the far-flung areas of the region, rural livelihood is experiencing an upswing, especially after the commissioning of the Indira Gandhi Nahar Paryojana (IGNP) that has transformed large parts of the driest and the dune-covered westernmost districts of Rajasthan into irrigated croplands, and rural electrification that has helped large-scale utilization of groundwater in potential aquifers for irrigated cropping. Linking of villages through road networks has ensured timely distribution of inputs and marketable produces, and better availability of credit facilities has allowed farmers to take greater risk despite the dangers of drought. This has happened despite the fact that human and livestock populations have increased manifold during the last five decades.

PRESENT SCENARIO

Between 1961 and 2001 the human population in western Rajasthan has increased by 194%, while the livestock density has increased by 72%. In terms of adult cattle units (ACU), the increase in livestock is by 51%. Human population density during 1961 was 37 km^{-2}, while the livestock density was 66 km^{-2}. By 2001 the respective densities increased to 108 km^{-2} and 113 km^{-2}.

It was essentially the progress in agricultural research, exploitation of surface and ground water and concurrent rural development programmes that helped not only to feed the growing human and livestock populations in a region with limited natural resources, but also to produce enough marketable surpluses to make agriculture more viable than before. The other major factor that helped to maintain a higher level of production was relative stability of the climate. Despite the fact that drought is an inherent feature of the arid zone climate (average 4 per decade), an analysis of rainfall pattern revealed more years with higher than average annual rainfall (360 mm) during the 1970s and the 1990s. A slight increase of 20 mm was recorded during the span of the 20th century. However, the region also experienced four moderate to severe drought years during those wetter decades; other decades since independence had 6 moderate to severe drought years each, emphasizing the extreme vulnerability of the region to climatic conditions. It is apparent that crop yield in the region presently depends on both technology and climate, while human and livestock numbers govern the supply and demand, and drought continues to play havoc with the system.

Current production levels: Broadly, the current production of cereals in Western Dry Region of Rajasthan (see Fig. 1), which contains the Thar Desert, is 2.52 million t, against a demand of 2.84 million t. In case of kharif pulses, the region has presently an estimated demand of 0.25 million t, while the production is 0.3 million t. Oilseeds production in the region is 0.8 million t, against an estimated demand of 0.36 million t. While pearl millet, sorghum and wheat are the major cereals, moth bean and moong bean are the major kharif pulses. Groundnut, sesamum, castor, rape and mustard, and Tarameera are the oilseed crops. The region's demand for fruits and vegetables are currently not very high. While the demand for fruits is 1 million t that for vegetables is 1.26 million t. Yet, the present production of fruits is estimated to be 0.01 million t (99% shortfall).

Income from different sectors: Commensurate with the production in western Rajasthan, there are large inter-zonal variations in income also (the agro-climatic zones within western Rajasthan are depicted in Fig. 1). An analysis of the production and income figures for 2004-05 shows that in all the four agro-climatic zones returns from agricultural sector contribute 26-43% of the total income, the mining sector provides 1.6-1.8%, while the 'other sectors' (including wages/income from service sector, business and allied activities) contribute 56-73% of the income. As is expected, the lowest total income from agricultural sector (including income from rainfed and irrigated crops, horticulture, bovines, ovines, and household industries) is in Arid Western Plain (Zone 1; 25.6%), where the 'other sectors' contribute 72.6%, and mining (mostly sandstone, limestone, gypsum and salts) 1.8%. This is followed by the Transitional Plain of Luni Basin (Zone 3), where the relative contributions of the three sectors are 29.8%, 68.6% and 1.6%, the Transitional Plain of Inland Drainage (Zone 2; 32.1%, 66.3% 1.6%), and the Irrigated North-western Plain (Zone 4; 42.6%, 55.6%, 1.8%). The croplands' contributions to these totals vary from 15.03% (Zone 1) to 30.18% (Zone 4). It is apparent that despite large part of Zone 4 being under irrigated crops for decades, the total income from agriculture does not have much of an edge over the 'other sectors'. In Zones 2 and 3, where groundwater irrigation is dominant, the croplands contribute 21.39% and 16.64% of the total income, respectively. The implications are that (1) despite more than 70% of the total working population being engaged in agriculture, it can hardly compete with the income from the service and business sectors, and (2) the opening up of opportunities in those sectors may gradually create an apathy among the inhabitants to till land, not only due to the poor assured returns, but also due to large uncertainties involved in input-output ratios from agriculture. The relative contributions of the different sub-sectors of agriculture to the agricultural income are also revealing (Fig. 14).

Income from components of agriculture: In all the four zones income from cropping provides 59-71% of the total agricultural income, while livestock rearing provides 28-42%. In Zone 3, the relative contribution from livestock is higher (42.30%) than in other zones, closely followed by Zone 1 (38.74%). In Zone 4 livestock sector contributes only 28.44% to the total income from agriculture. When analysed on income per hectare basis, the contribution from rainfed croplands dropped to 2.71% in Zone 1, and to 7.42% in Zone 4, as compared to 34.71% and 22.62% from irrigated cropping in the two zones, respectively. Rainfed croplands in Zones 2 and 3 that lie in the wetter fringe of the desert, contributes 7.30% and 6.96% of the zones' agricultural income.

Rainfed system: The ovine population, dominant mostly in rainfed areas, contributes <1% per animal income to the per unit income from agricultural sector in the four zones. Bovines, dominant in irrigated tracts, contribute 22-33% per animal income, but require higher maintenance cost than the ovines. Household industries, which include wool and leather processing, and depend mostly on ovines, contribute 12-24% of the per unit agricultural income, the highest being in Zone 1. Thus it strengthens the economy of ovine population that has very little maintenance cost, survives mostly on degraded pastures and rainfed croplands, and provides livelihood even during the droughts. Horticulture, with limited presence, is generally practiced on sub-marginal rainfed lands, and contributes 16-22% of the per unit income from agriculture. Together with the ovines and household industries, it contributes to the strength of the low-income generating rainfed croplands, which is organic by default. The three sub-systems together needs a holistic farming system approach for development, with improved rain water use efficiency, stress-resistant crop varieties and land management practices.

Irrigated system: The irrigated croplands, though accounting for 23-35% of the agricultural income (per ha basis), are largely a result of groundwater exploitation that is nearing exhaustion in many districts. The higher per ha income from irrigated areas in Zone 1 (Rs. 95591), Zone 2 (Rs. 48852) and Zone 3 (Rs. 29810) than in Zone 4 (Rs. 28264) possibly reflects a shift from the traditional cotton/cereal cropping system in Zone 4 to the growing of high-value cash crops in the other zones. Falling groundwater reserve, uncertain canal irrigation in lower commands, higher input costs and salinity problems threaten to upset the income advantage of the irrigated tracts in near-future. The foremost requirement in this system is irrigation water use efficiency, integration of livestock economy with that of cropping system, and a close soil monitoring and amendment programme due to the depleting soil nutrient balance.

Income-based major clusters: Non-hierarchical cluster analysis of the districtwise income data from different sectors revealed a tendency to include most of the sandy tracts from Barmer in the southwest to Churu-Sikar in the northeast in one cluster, club Jodhpur and Nagaur districts in another cluster, Ganganagar and Hanumangarh districts as a third cluster, and isolate Jaisalmer district as a distinctive one. Broadly, it mimics the two major agro-climatic regions present in the desert: the Western Dry Region, and the Trans-Gangetic Plain Region, with a highlight on the very dry Jaisalmer region.

System strength and vulnerability: The above analysis suggests not only the extreme vulnerability of rainfed system, but also its potentials that need to be carefully exploited as a crop-livestock-horticulture based farming system for a sustainable future. It also hints at the capacity of the irrigated system to produce much higher than the rainfed system, and 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. However, the sustainability of the system is becoming uncertain and adverse input-output ratios may aggravate it. 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.

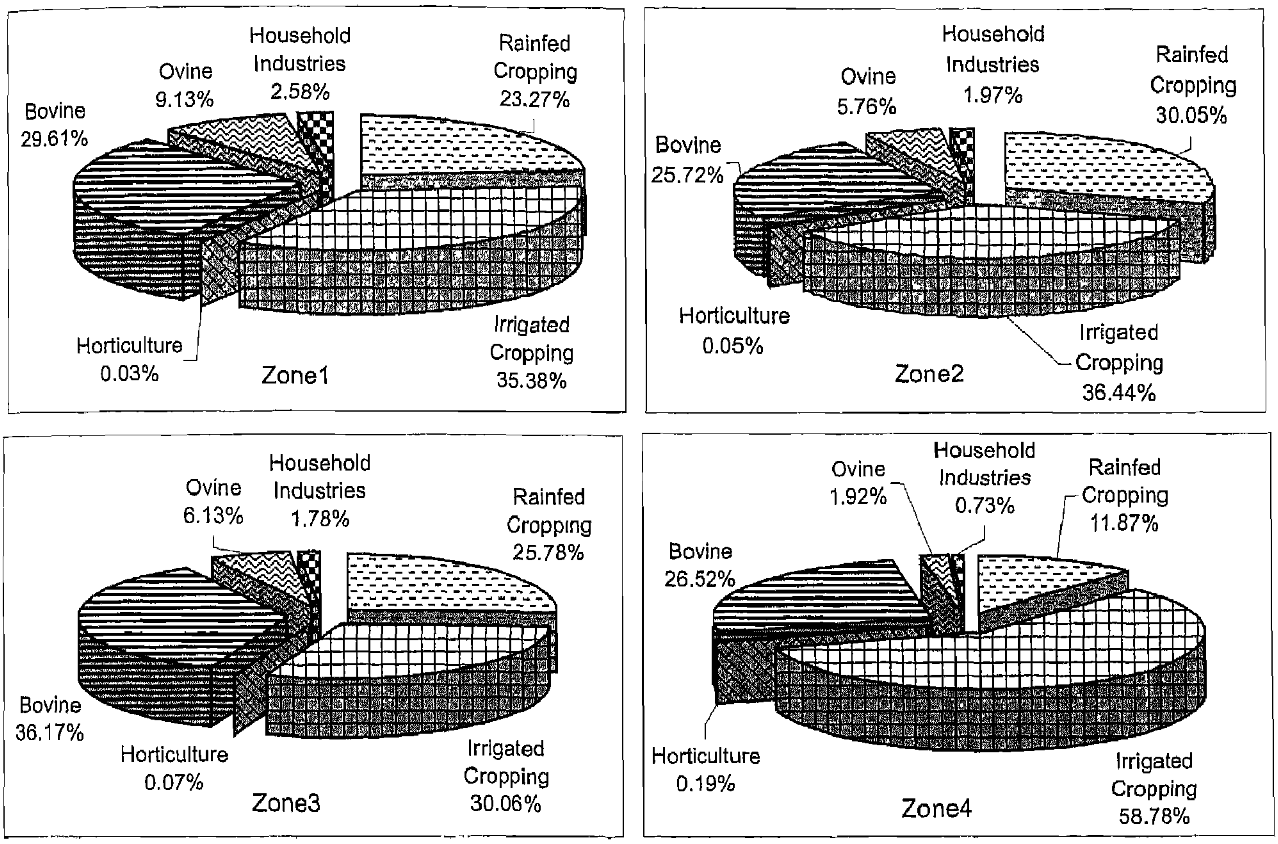

Fig. 14. Percentage of total income from agriculture in four agro-climatic zones of western Rajasthan.

Impact of growing demand on land resources: To cater to the needs of the increasing population the net sown area has been increased from 39% (1960-61) to 50% (2001-02), mostly at the cost of the fallow lands. Also, with increasing population the average size of land holding per household has decreased from 17.77 ha in 1951 to 14.69 ha in 1961, 10.20 in 1971 and 6.0 ha at present. The overall decline during the last four decades is 57%. If this trend continues, it may fall to <4.0 ha by 2020. Since land distribution is uneven (11.2% households own 50% of the total land, whereas 47.3% hold only 10% of the total), this meant that pressure on croplands became higher for majority of small and medium farmers, and it became increasingly difficult for them to keep the land periodically fallow for restoring soil nutrients levels. Allocation of more land for cropping, severe reduction in short and long fallowing practices, expansion of cropland to marginal lands and higher incidence of deep tillage are leading to soil quality deterioration. Soil organic carbon (SOC), phosphorus (P) and potassium (K) stocks are getting depleted fast. There has been phenomenal increase in the use of tractors during the last two decades (i.e., from ~7,300 in 1980 to >132,000 in 2002). Deep ploughing of sandy soils using tractors, tractor ploughing up to the middle and upper slopes of the high sand dunes, uprooting of naturally growing shrubs and grasses on sand dunes for fuel and fodder, and overgrazing are leading to high wind erosion. There is also widespread degradation of vegetation. Most of the permanent pastures have been very severely exploited for fuelwood and fodder, and through unrestricted grazing by a large number of livestock (23 million; density 113 per km^2). Industrial effluents and mining are also adding to land degradation. Currently ~61% area of western Rajasthan is moderate to severely affected by desertification, especially through wind erosion (50%), water erosion (9%), and water logging and salinity (2%).

Impact on water resources: Expansion of irrigated agriculture outside the canal-command areas has adversely affected the groundwater reserve (Fig. 15). Aquifers in 6 out of 12 districts in the region are now totally over-exploited, where deep-seated poor quality water is being increasingly used mostly for irrigating the high-value crops in sandy terrain.

There has been >150% increase in the use of groundwater during the last one decade. So much water is now used for producing irrigated crops that as per estimates of the State government a mere 10% saving of it would be enough to solve drinking water problem. Use of high-RSC water has resulted in sodicity of soils, which has reduced the production potential of the land. Over-use of water in the canal-command areas has led to water logging and soil salinization, especially in the IGNP areas, where the occurrence at shallow depth of impervious layers of clay, gypsum, carbonates, etc., has added to the problem. It is estimated that out of 3.6 million ha area potentially sensitive to water logging in IGNP area, ~50000 ha is already affected. Very soon the southern parts of Jalor and Barmer districts, covering the Luni delta, will get irrigation water from the Narmada Canal system. The Lift Canals on the right bank side of the Luni are proposed partly through a system of saline plains and Ranns (saline depressions). If constructed, and if no remedial measures for water logging and salinization are taken from the planning stages here, large areas in the fertile lower Luni plains will soon be out of cultivation.

Changes in pest complex in canal command areas: Introduction of IGNP has led to changes in pest complex. Rodents like *Bandicoota bengalensis* and *Nesokia indica* have migrated from irrigated regions of Punjab to northern Rajasthan and typical desert rodents like *Meriones hurrianae* and *Gerbillus gleadeni* have almost disappeared. Irrigation has also created favourable environment for insect multiplication. Mesic insects like jassids and defoliators are replacing the traditional xeric insects.

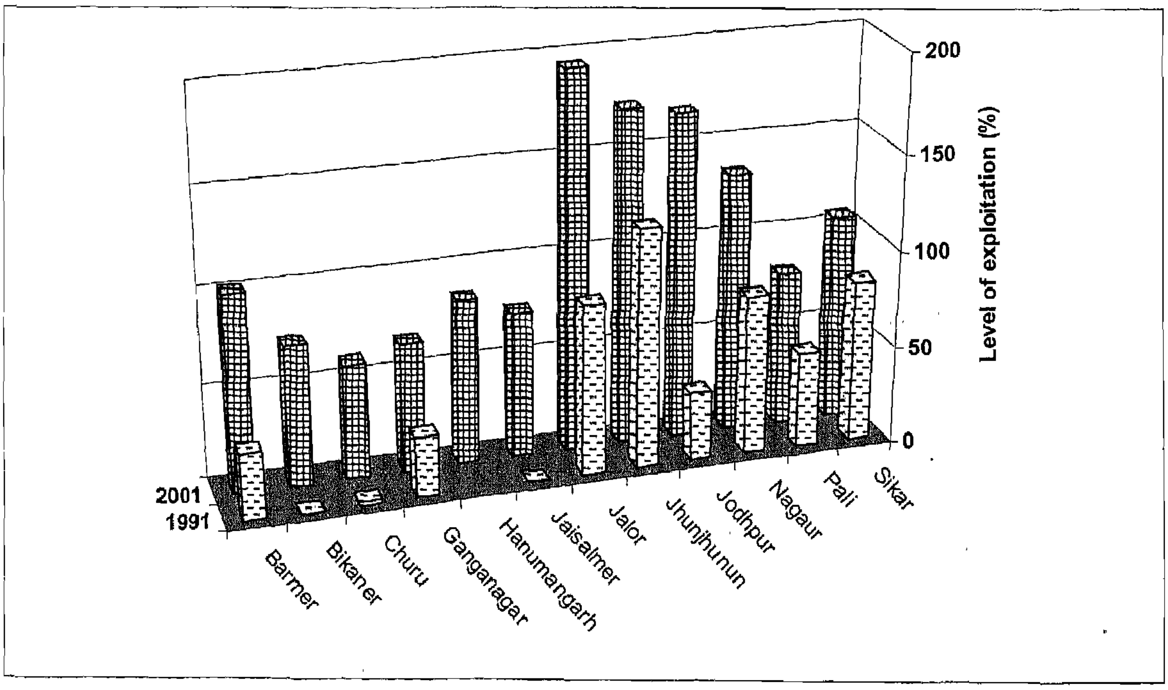

Fig. 15. Groundwater exploitation in western Rajasthan (1991-2001).

FUTURE SCENARIOS

Scenario I (Climate unchanged; population and technology increase): It is now necessary to find out the impact of the different factors on future. If we consider the climate to remain unchanged and allow the population to increase at the present rates, and also allow 10-20% adoption rate/year of new and upcoming technologies, the future production of cereals, pulses and oilseeds will be more than sufficient to meet the regional demand. There is a likelihood that human population will increase from the present 22.5 million to 33.6 million, and its density from 108 to 161 (Fig. 16). The livestock population is also expected to rise significantly, the four major components of cattle, buffalo, sheep and goat together registering a rise from ~23 million in 2003 to 41 million in 2025 (Fig. 17). The most spectacular change has so far been in the case of buffalo population which has increased from 0.8 million during 1956 census to 3.2 million in 2003. At this rate it is expected to reach 6.4 million by 2025, while cattle population may increase from the present 4.1 million to ~7.0 million. The production of buffalo milk may surpass that of cow milk, especially in the irrigated areas.

To adjust to the witnessed changes, and assuming that livestock-based farming system will gain dominance due to relative advantage of household economics in the face of climate change and resource degradation, efforts are to be made to provide good quality feed and encourage stall-feeding system. Unfortunately, there is at present about five-fold shortfall in the feed resources availability in the Western Dry Region (Fig. 18), and the available feed is largely of poor quality. The scenario till 2020 is not very encouraging either. Considerable efforts are required to bridge the feed resources gap and to make livestock rearing more sustainable and profitable. The quality of livestock is also continuously deteriorating in terms of genetic purity. For instance, one of the hardiest and best cattle breeds, the Tharparkar, is now estimated to have only 10% purity. These and other related problems need to be addressed to make livestock-based farming system a viable proposition.

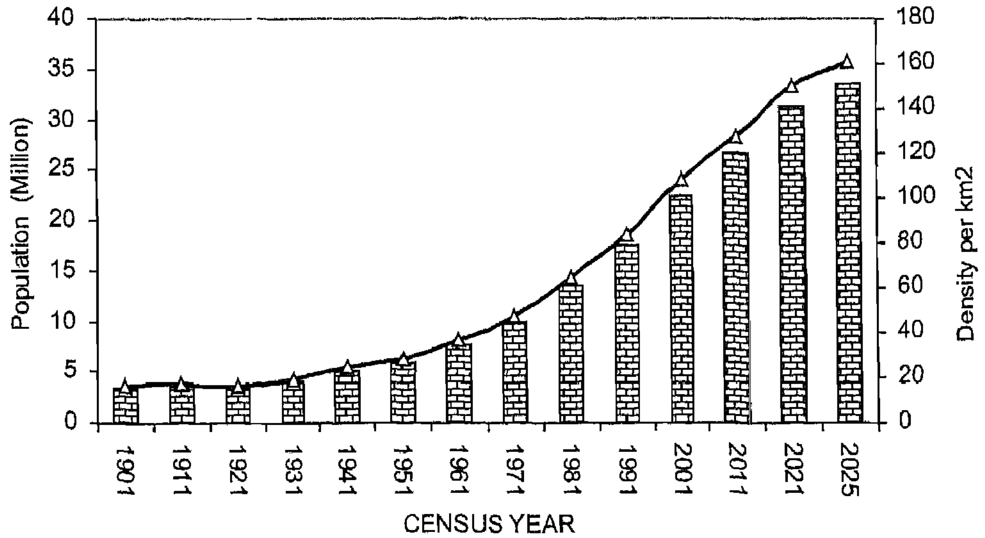

Fig. 16. Changes in human population density in western Rajasthan with time.

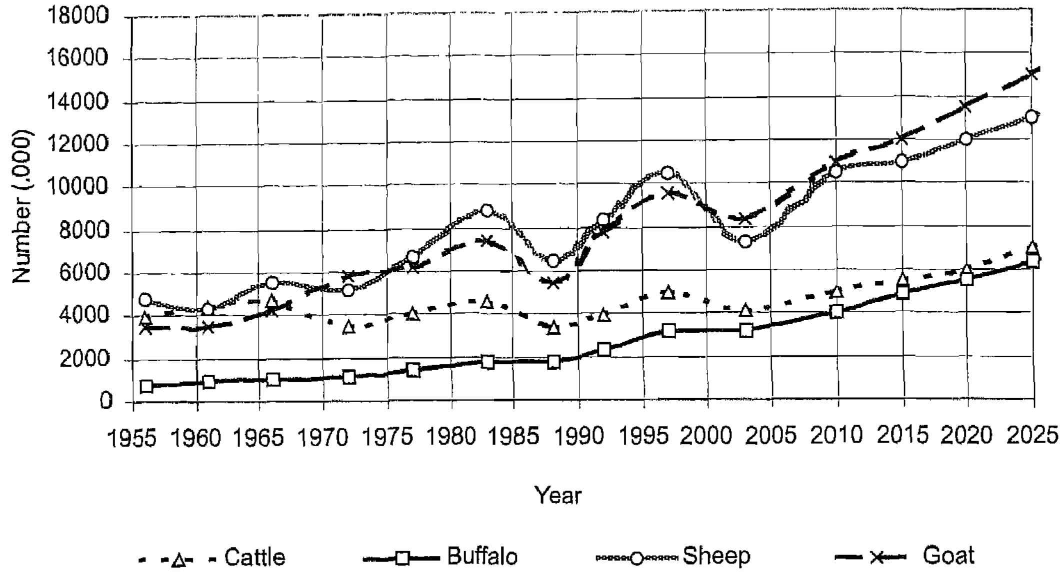

Fig. 17. Changes in livestock population with time.

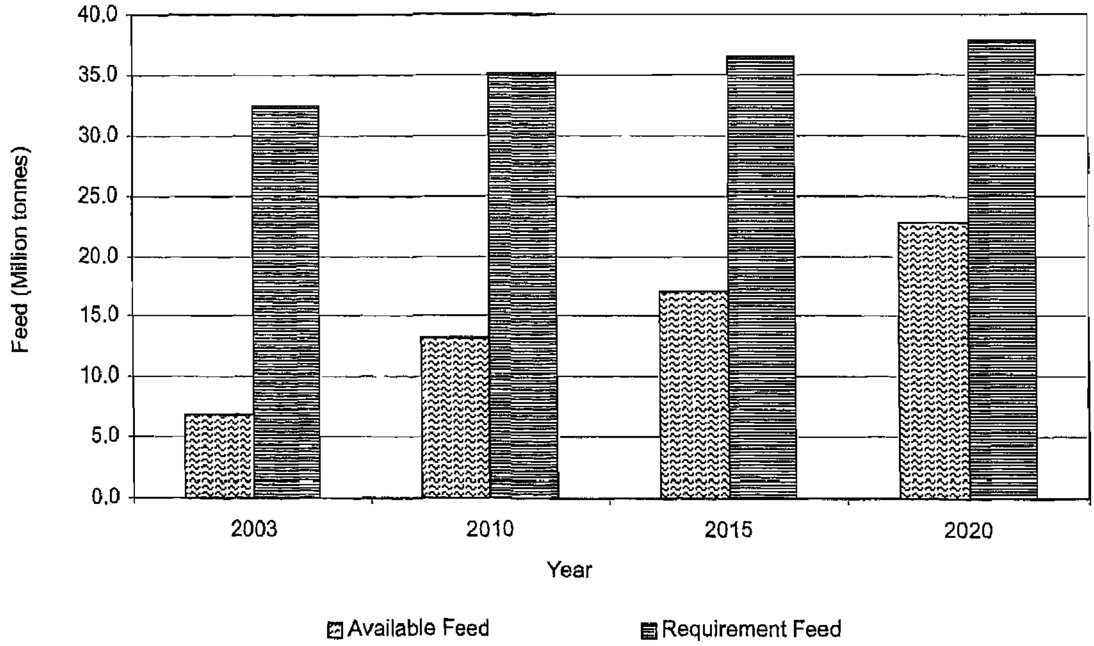

Fig. 18. Feed availability and requirement in Western Dry Region.

The net sown area is likely to increase to 55% of the total geographical area, while fallow lands will constitute only 11.5%. Forest area may increase to 4.5%. Culturable wastes and pasture lands, constituting the major grazing areas, may decrease to 20%, and areas not available for cultivation due to increased non-agricultural uses may increase to 9% (Table 9).

Production of cereals and pulses is estimated to increase by 29% and 96%, respectively, than the local requirement, while oilseeds production may go up by 600% more than the local demand. Fruit and vegetable production will, on the other hand, is expected to register a shortfall of 98% and

66%, respectively, from the local demands. The most crucial factor to sustain these estimated changes is irrigation facility, and thus the assured supply of water, which is becoming scarce by the day. At present large parts of the irrigated tract in the region is under groundwater irrigation, but with the over-exploitation of water and negligible recharge, many of the aquifers have already become almost dry. The scenario is likely to become worse by the next decade.

Table 9. Land use trends in western Rajasthan (%)

Year	Net sown area	Cultivable waste land + pasture land + trees	Fallow land	Area not available for cultivation *	Forest
1960	39.42	26.03	19.49	14.28	0.78
1970	44.75	25.53	14.50	14.44	0.78
1980	47.44	28.76	14.18	8.25	1.37
1990	49.55	26.37	13.67	8.55	1.86
2000	51.56	24.07	13.15	8.72	2.50
2010	53.56	21.85	12.55	8.90	3.34
2025	55.00	20.00	11.50	9.00	4.50

*Area not available for cultivation includes barren lands and area put to non-agricultural uses.

Among the livestock products, milk production is showing signs of improvement, and the surplus is likely to be very high. The current demand for milk in the region is 1.42 million L, but the production is 2.70 million L, providing a surplus of >1 million L for selling outside the region. If the trends continue, the region is expected to have 167% surplus production by 2025, when meat production could be 125% higher than the demand and wool production 23%. Despite this, dairy industry and milk marketing is still not very well organised, nor is the livestock-based economy. Estimates have revealed that production of wool, especially from the small ruminants, as well as production of meat is increasing steadily. The wool production from the region is currently 12 thousand t, while that of meat 30 thousand t, which are likely to increase to 25 thousand t and 125 thousand t, respectively by 2025. Marketability of wool will depend on the quality of the wool and the likely competition with synthetic products, but the meat production and marketing appear to have a promising future. Livestock-based industries have a bright future provided the production to consumption stream is well managed, including creation of better facilities for feeding, breeding and sheltering the animals, processing the products like milk, meat and wool, as well as the 'wastes' like hide and skin, bones and other parts, and development of infrastructures for fast movement of perishables.

Western Rajasthan has vast sandy, rocky/gravelly and other categories of wastelands (Fig. 19). Although the wastelands are expected to decline to ~20% of the total land area, many of these provide excellent opportunities for development of silvo-pasture, horticulture, medicinal plants and other alternate land uses. The major control is that of the rainfall, which increases from west to east, and provides greater sustainability to grasses and shrubs in the west, trees in the central part and crop diversification in the east, as well as of the livestock-based systems vs. arable-crop-based systems (Fig. 20).

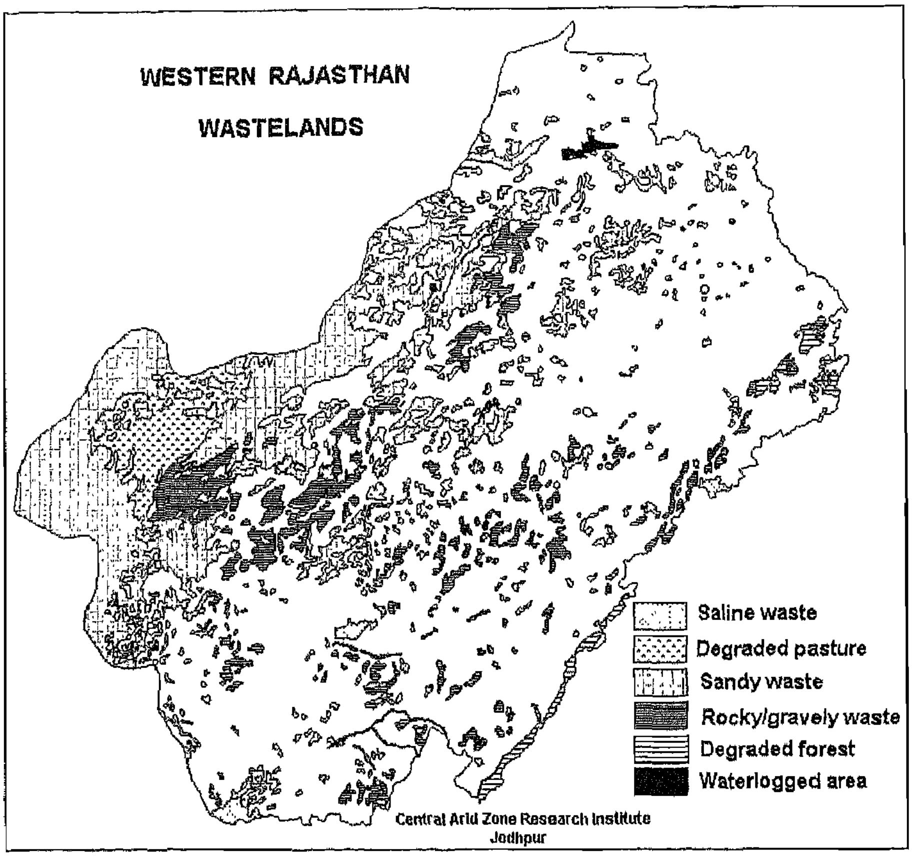

Fig. 19. Wastelands in western Rajasthan.

With time, as croplands face a number of challenges, including that from the changing scenario of WTO regime, expanding urban spaces and industrial uses, the wastelands are expected to receive a major attention for expansion of agricultural production base, especially for cash crops, provided these are also not committed to non-agricultural uses. The threat that may upset the above presumptions is climate change.

Scenario II (Warmer climate; population and technology increase): Global climate change, especially towards a much warmer climate, is now an established fact. This has been re-confirmed by the Intergovernmental Panel on Climate Change (IPCC) in its summary of the Fourth Assessment Report, published in February 2007. Results from a number of General Circulation Models have suggested that India will be affected by this global climate change, and that agriculture will be particularly impacted. Yet, very few studies provide in detail the climate change impacts on Indian agriculture, or recognise vulnerability of the country's economy to potential changes in climate. Despite significant progress made in food grain production, the per capita net availability of food grains in the country still fluctuates between 400 to 500 g day^{-1}, which is way below the international standard. An adverse change in climate may further reduce the availability, unless remedial measures are taken through technology upgradation. Far less is known about the ability of neighbouring developing countries to adapt to climate change.

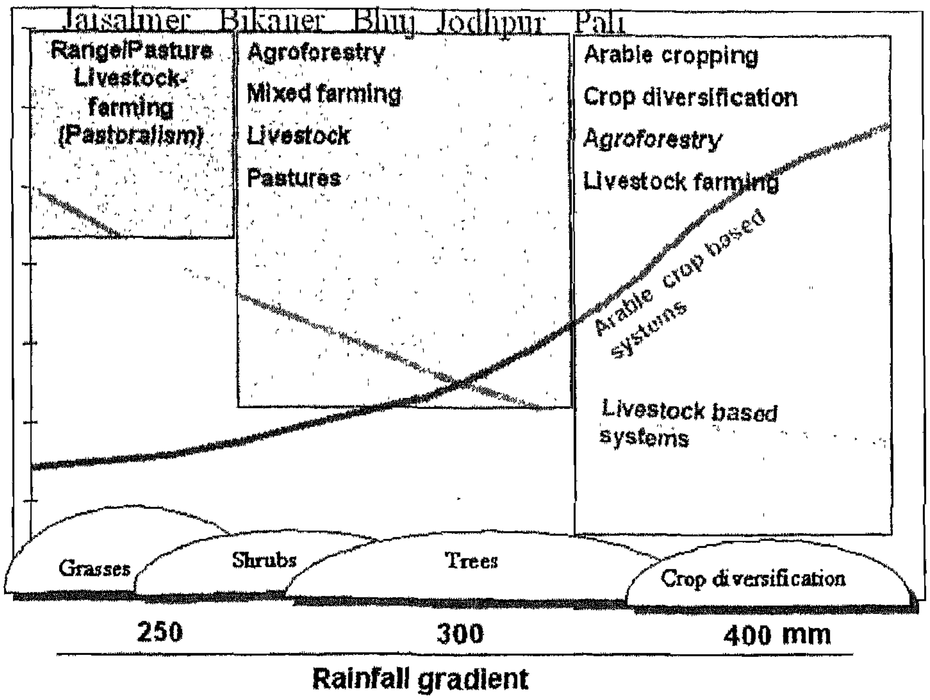

Fig. 20. Rainfall gradient and relative importance of different production systems in western Rajasthan.

Surface air temperature in most parts of India has increased by about half a degree during the second half of the 20th Century. The most crucial change has been predicted to be in the enhanced atmospheric CO_2 concentration from ~370 ppm at present to >450 ppm by 2050 that should lead to higher water use efficiency of crop plants and accelerated crop development, but could lower the biomass and seed production efficiency. Higher temperatures, where in association with reduced rainfall, may increase the evapotranspiration, which will impact the hydrological cycle. FAO (1991) has estimated that globally a 25% decrease in rainfall and a 5% increase in evapotranspiration can reduce the irrigated area by 75%, aggravating the situation more in arid areas and in developing countries.

Simulation studies by Hadley Centre (UK) and IITM (Pune) suggest that temperature is likely to gradually increase by 2-5°C across arid Rajasthan, but southern Rajasthan and adjoining areas of Gujarat experiencing smaller increases than the north. Apart from increases in summer temperatures, there is likelihood of a gradual increase in winter temperatures. In the next 50 years monsoon rainfall is likely to decline gradually by 20-30% in the northwestern part of Rajasthan and adjoining Punjab, while the eastern fringe of arid Rajasthan and adjoining Haryana may experience an increase of up to 25%. At the same time winter rains may gradually increase by 20-40%. Arid Gujarat and adjoining south Rajasthan, on the other hand is likely to experience ~25% higher monsoon rains, as well as higher winter rains. There is also the probability of high magnitude droughts and floods. Such a scenario would most likely lead to higher wind and water erosions, as well as changes in vegetation composition and its degradation. Soil moisture status during the cropping seasons will also experience a change. Coastal areas of arid Gujarat are likely to experience sea level rise and consequent loss of land (Hadley Centre, UK, 2005, *Key Sheet 2 on Climate Change in India*; Rupa Kumar, K. *et al.*, 2006, *Current Science*, vol. 90, pp.334-345; IPCC Summary Report of Working Group 1, 2007).

If and when such changes take place, these will surely impact the arid land agriculture to a great extent, and in turn the livelihood security of the farming communities, as well as the food security of the region. The yield opportunities of increased CO_2 are likely to be available for a shorter period when the rise in temperature will be small, and will gradually be lost with the increased temperature. Since the bio-physical resources of the region are already in a delicate balance with the prevalent climate, major changes in temperature and rainfall distribution pattern, as well as the occurrence of high-magnitude droughts and floods would reflect sharply on the soils as well as the performance of existing plant species, including the crops. If not tended properly, many of the species may even become extinct. Yields of traditional and conventional crops are expected to go down by 20-30% unless remedial interventions are made.

Averaged over many years, runoff is generally equal to the difference between precipitation and evapotranspiration and hence to the convergence of horizontal water flux. Irrigation to cropland disturbs this balance. Almost all the climate models agree that areas of decreased runoff have increased from the late 20th century to the 21st century (10-40%). Significant part of the hydro-climatic change has been externally forced (Nature (2005) 438:347-350). Although virtual water trading is possible towards dry regions, it may not compensate water stress. In western Rajasthan the retreating Himalayan glaciers will, after a few decades, impact the water volume in IGNP, while the demand for Narmada Canal water in neighbouring states may add to the uncertainties in irrigation, especially as groundwater reserve is already under immense stress. Globally, the expected outcome of such changes is thought to be a migration from rural areas to the urban centres for a secured livelihood (Science (2006) 313:1068-1072).

Simulation studies suggest that temperature rise will adversely affect the potential as well as water-limited yields of pearl millet across the region, while decline in rainfall will have more adverse effect in the relatively low rainfall areas having light textured soils (e.g., Jaisalmer and Jodhpur) as compared the areas which receive moderate rainfall and have medium textured soils (e.g., Pali). Some of the likely impacts on the crop's performance and issues of adaptation are summarised below (Table 10).

Based on the current understanding of climate change simulation results, we can broadly divide the northwestern hot arid zone into three major sub-zones: (1) the hotter and very dry north-western Rajasthan and adjoining Punjab, (2) the warmer and moderately wetter arid Gujarat and adjoining south Rajasthan, and (3) the hotter and slightly wetter eastern fringe of arid Rajasthan and adjoining Haryana. The problems and potentials of the different agro-climatic zones falling within these sub-zones will need close monitoring.

Likely impact of the changes on GDP: Net revenue from agriculture is sensitive to weather variations and climate change, especially the changes in temperature. Revenue losses are estimated to increase with warming, even assuming that increased rainfall in appropriate amounts during crop phases, can moderate the impact of temperature rise to some extent. With +2.0°C rise in mean temperature and a +7% increase in mean precipitation, the GDP (gross domestic product) in agriculture is likely to fall by 7%. With 3.5°C rise in temperature and 15% rise in rainfall, the GDP will possibly fall by 25%, leading to food crisis and poverty. In areas experiencing temperature rise without any increase in rainfall, the revenue loss is expected to treble with each degree rise in temperature, the revenue decline with 1°C rise being estimated as 3% (Kumar and Parikh, 1998; World Bank Tech. Paper 402).

Table 10. Effect of climate variability on pearl millet crop performance and adaptation options

Climate parameters	Effects on crops and natural resources	Adaptation options
Late onset of rains	Shorter rainy season, risk that long duration variety will run out of growing time	Early-maturing varieties, exploitation of photoperiods, location specific balanced nutrition at planting
Early drought	Difficult crop establishment and need for partial or total re-sowing	Crust breaking, balanced nutrients at planting, organics application, water harvesting and runoff control, delay sowing (but poor growth due to N flush), exploit seedling heat and drought tolerance
Mid-season drought	Poor seed setting and panicle development, fewer productive tillers, reduced grain yield per panicle/plant	Use of pearl millet variability; differing cycles, high tillering cultivars, optimal root traits, etc; water harvesting, reuse and in situ conservation
Terminal drought	Poor grain filling, fewer productive tillers	Early-maturing varieties, optimal root traits, fertilizer at planting, water harvesting and reuse
Excessive rainfall	Downy mildew and other pests, nutrient leaching	Resistant varieties, pesticides, N fertilizer at tillering
Increased temperature	Crusting/ soil capping, poor plant population (desiccation of seedlings), increased transpiration, faster growth	Heat tolerance traits, crop residue management, P fertilizer at planting to increase plant vigour, large number of seedlings per planting hill
Unpredictability of drought stress	Poor crop establishment (desiccation of seedlings), improper/ faster growth	Phenotypic variability, genetically diverse cultivars, agro-forestry
Increased CO_2 levels	Faster plant growth through increased photosynthesis, higher transpiration	Promote positive effect of higher levels through better soil fertility management
Increased occurrence of sand/ dust storms at onset of rains	Seedlings buried and damaged by sand particles	Increase number of seedlings per planting hill, mulching, ridging (primary tillage), wind breaks
Increased dust in the atmosphere	Lower radiation, reduced photosynthesis	Increase nutrient inputs (i.e. K)

To prepare strategies to meet the fast-changing development initiatives and their impact on the natural resources and socio-economic conditions, as well as to withstand the perceived climate change impacts, we need to re-adjust/re-orient our research as best as possible under given set-up. The focus will largely be on the western part of Rajasthan (and the adjoining parts of Punjab, Haryana and Gujarat) because of its high vulnerability to drought and desertification that might change for the worse. Since the likely impacts are yet to be fully perceived, and uncertainties are more, the adjustments are to be made with caution and over a period of time as the scenarios unfold.

Elsewhere in the country, the coastal Tamil Nadu is expected to have ~4°C rise in the temperature and 10% increase in rainfall by the 2070s, the likely worst affected area being around Tuticorin and the interior Tamil Nadu near Karur. The traditional arid areas of Ananthapur and Bellary, on the other hand, are likely to experience >100% rise in winter rainfall, although the annual total may not rise beyond 20-30%. Summer rains are likely to decrease by ~25% in the interior Karnataka and coastal Tamil Nadu. Apparently, arid domains in southern India would widen to some extent.

IMPLICATIONS FOR FUTURE RESEARCH NEEDS

The projections made above have deeper implications for agricultural research. The areas that need greater attention are as follows.

- Need to develop increased heat tolerance in high-value, temperature-sensitive crops.
- Improving the water use efficiency of crops and other economic plants to withstand rainfall abnormalities.
- Finding measures to increase production potentials in rainfed areas.
- Management strategies to face the likely challenges of increased frequencies of droughts and floods.
- Strategy to minimize the runoff in areas of increased rainfall to capture benefits particularly for winter crops.
- Strategy to increase green cover in the sandy terrain to minimize wind erosion and thus soil nutrient loss.
- Research for mitigating the likely increased pest infestations as a result of warmer winter climate.
- Improving the animal production system to face the challenges of more uncertainties.
- Development of sound strategies for crop diversification, integrating with livestock sector for a holistic farming system, agro-processing, and marketing to stabilize the income and improve rural livelihood
- Research on other climate-sensitive sectors, including energy and forestry sectors to understand more fully the economic impacts of possible climate change in arid areas.
- Management strategies for pastoral families on migration, who may face newer challenges and resistance due to more scramble for scarce resources, and who may be more unwelcome.

7. PERSPECTIVE – A WAY FORWARD

Pressure on finite and limited natural resources of the Indian arid zone is increasing due to rising human and livestock population, as well as demands driven by development and affluence. The conflict is between demand-driven economic compulsion forcing over-exploitation of fragile natural resources and need for their conservation and sustainable utilization. Growing imbalance, leading to resource degradation and desertification, is a cause for serious concern. As we have analysed in Chapter 6, changes in climate are also putting more pressure on the resources, and introducing more uncertainties in the system.

Considering the challenges likely to be introduced in the system by climate changes, as well as the challenges of increasing population pressures, demand from other sectors of the economy for land and water resources, more attractive and assured livelihood options from the non-agricultural sectors that pull manpower, and likely faster degradation of resources as a response to higher demands under a uncertain climate, we may have to produce more from a reduced land area with an adverse water balance and with a reduced manpower available for agricultural sector. Meeting the challenges then demand not only better management practices but also a vast improvement in the agricultural technologies. We have to understand what kind of knowledge is required by policy makers and by the society at large. The knowledge base and the research capabilities are to be enhanced and upgraded, and the scientific reasoning more strengthened. It also requires improved communication between the scientists and the policy makers to ensure that expertise is translated into actions that address the future challenges.

For enhancing factor productivity of land, a number of plants, animals and technologies that are exotic to the zone, have been introduced without paying much thought to the demands of the introduced species on the available scarce resources, as well as ignoring the competition in the regional market. Examples are the growing of irrigated crops like wheat and mustard that are fast depleting the groundwater, or the rearing of buffaloes despite scarcity of fodder, feed and drinking water. Enlarging the mustard production base is now leading to a glut in the market, and the consequent frustration of the farmers. Lessons have to be learnt from the past before it is too late, as to how people have survived without depleting or over-exploiting the natural resources. The Institute has developed a number of technologies, adoption of which is gradually improving the scenario (e.g., sand dune stabilization and shelterbelt plantation that are helping in wind erosion control, drought-resistant and short-period crop varieties, nutritious grasses, fruits, etc., all of which are in demand). However, a lot more is to be done to cater to the changing demands of the time. Some of the sectors where more attention is required, are highlighted, but the list is not exhaustive.

Improved understanding of the system changes: Arid land management and desertification control are the two major objectives of the Institute. To achieve these goals under a fast changing scenario, it is necessary to increase our understanding of the nature, extent and severity of drought and desertification, and vulnerability of land and populations to drivers of changes, as well as develop improved monitoring mechanism for better spatial planning.

Strengthening of farming systems: For sustainability of arid farming systems, the symbiotic relationship between natural environment and arid agriculture is to be perceived and re-emphasised.

Our endeavour should be to increase the potentials of arid land production systems without depleting the local biodiversity, mining of soil and water resources, or hampering the system's resilience capacity. It is necessary to develop an integrated livestock-based organic farming system with a focus on pasture, horticulture, medicinal plants and bio-fuel plants, especially for the rainfed areas. In such a system a major portion of the culturable wastes can be diverted to horti-silvo-pasture. Increasing the availability of organic manure from livestock will help greatly in restoring soil fertility. Sand dunes and other degraded lands (both government and farmer-owned), when put under grasses, shrubs and trees, with proper management, can become inexhaustible sources of forage in this region. This goal can be realized through a mission-oriented on-farm research with a farming system perspective and a bottom-up (farmer-first and farmer-last) approach.

Structural changes in cropping system: By replacing conventional low-yielding crop varieties with improved high-yielding ones, and by optimizing other agro-techniques, the areas under arable crops can be reduced by 20-30% without sacrificing total grain production. For this, one of the major requirements is to genetically improve the adaptation, stress tolerance and other necessary traits of the plants to provide higher yields of grain and/or fodder. Developing the short-duration and resistant cultivars through selection and bio-technological mediation will ensure that whatever is planted/sown does not become a victim of uncertain weather. When effective, higher crop production can be expected from a smaller area to meet market demands, and scope for diversification and sustained total productivity through bringing sizeable marginal lands under perennial tree, shrub, grass and horticultural crop production system will be possible. This structural change assumes more importance due to the growing evidence of increase in temperature, reduction in rainfall in large areas, enhanced periods of drought, high-intensity and shorter duration rainfall, and shorter effective growing period. Arid regions are organic by default and hence advantage of organic farming needs to be encashed, particularly for endemic condiments, herbs and medicinal plants. A shift from the high-input, economically unstable agriculture to a low-input, stable and economically sustainable agriculture will thus ensure not only rural livelihood, but also the health and wealth of the land.

Rainwater conservation and water use efficiency: Conservation and efficient management of rainwater will help to stabilize/increase the productivity. However, if climate worsens, the production may fall short of meeting the growing demands of food. The need is to develop cultivars and agronomic practices that have higher water use efficiency. A shift to production system that is more remunerative while being sustainable may be desirable. On a spatial scale, watershed management, with appropriate mix of different components of the agri-horti-silvo-pastoral system, crop diversification and better utilization of the rainwater through soil and water conservation structures, needs to be propagated.

Adding value to products for changing market demand: Value addition to the agricultural produces will be more remunerative when networks and environment for marketing are more efficient and favourable. Agriculture needs to be more market-driven and economically viable, but at the same time more environment-friendly that conserves natural resources, and depending more on the on-farm resources rather than on the off-farm resources like chemical fertilizers, pesticides, fossil fuel, etc.

Value addition to horticultural products: Although improved varieties of Ber, pomegranate, Aonla, etc., have been developed, these are mostly sold in the market as raw products. Adding value to these fruits will vastly improve their market potentials. For example, if Ber fruit is processed as

Table Dates are done, and packaged individually and sold as toffees, there will be more demand for the product that will not only vastly lengthen the period of its use, but will also enhance the development of Ber nurseries, thereby ensuring rural employment, nutritional security of the people, soil fertility build up and environment conservation.

Value addition to livestock products, especially the ovines: Ovines are mostly the drivers of small and marginal farmers' economy in the region. While the stock is partly sold by the stakeholders to brokers for meat purpose, the milk is consumed at home due to its perishable nature and odour. Through research it has been possible by CAZRI to eliminate the odour and to prepare products like kulfi, paneer, whey, etc., with a shelf life that is much higher than previously. This has opened up the scope for improving the sheep and goat based economy of small holders. Further improvements are now necessary, backed up by market demands, so that the potentials of the sector could be exploited to the best possible limit.

Creating a value chain for livestock products: As has been emphasized, one of the strength of the arid region lies in a developed livestock-based industry, because it can sustain on the scarce resources of the region, and can absorb the shocks of drought more efficiently than the crop sector. However, unlike the crops, most livestock products (milk, meat, etc.) are highly perishable, and need a different pathway from technology to management to market than is considered for the crop-based system. For a holistic development, it is necessary to not only improve the animals through improved breed, feed resources and shelter management, but also to improve the range practices and product processing. Preserving animal products and their transportation to ultimate consumers, is highly energy-intensive. This is a major limitation in developing the sector and delivery of the goods to consumers, despite the large demand. Therefore, technologies for enhancing the shelf life of the products and their proper storage and transport are to be improved upon. Development of the sector also requires huge improvements in infrastructures, as well as market research.

Improved livestock management: A practice of culling unproductive livestock for value addition that generates employment and family income, and saves precious fodder for the productive milching animals, is to be encouraged, while the need for preservation of the purity of breeds is to be taught across social taboos.

Harnessing the potentials of economically important local plant materials: The plant biodiversity of the arid region has not so far been adequately 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* (tumba), *Salvadora oleoides*, *Acacia senegal*, etc., have received belated attention for medicinal, industrial and food values. Technologies for deriving benefits from these and other local plant materials need to be developed, as the chances of their survival and production under a worsening climate are better than many introduced ones.

Efficient harnessing of non-conventional energy sources: The fuel energy used in rural household in the arid areas is still overwhelmingly based on local trees and shrubs, which put immense pressure on the survival of natural vegetation. Introduction of *Prosopis juliflora* during pre-independence period, though blamed for its aggressive colonization habit, and its fast spread across the arid lands during the last five decades, has provided some relief to the households. Since the plant does not need any maintenance, occurs in wastelands to provide a green cover, sequesters carbon, and has a high calorific value, renewed efforts to systematically develop a technology for cheap, small-scale, *Juliflora*-based fuel for the rural communities would be helpful. Since it is very difficult to eradicate the plant, encouragement to research that helps its controlled growth, propagation of the uses of its pest-resistant timber, or the processing of its pod as a livestock feed will open the ways for converting the adversity into a strength and ensure better living with the plant.

Since the region is also well endowed with solar and wind energy, there is also scope for their systematic harnessing for agricultural and domestic uses. Solar appliances have been developed for cooking food and feed, heating water, making candle and drying agricultural produce. Research efforts are now being made to utilize photovoltaics, chemical cells and other clean energy sources for irrigation, etc. Efforts are needed to exploit the research potentials of nano-technology to develop cheap solar devices. Improvements/modifications in greenhouse construction for arid regions, and linking it with solar devices for maintaining ambient environment, will play a crucial role in increasing the per unit production of crops at a reasonable cost.

Strengthening traditional knowledge: Traditional values and practices like protecting trees and animals, as well as the *orans* (sacred forests/ grazing lands attached to deities), construction of water harvesting structures like *Khadin* and *Tanka,* practices of long fallowing, etc., have undergone rapid decline during the last few decades. Many of these survival and resource conservation strategies are presently under severe threat or are no more practiced because of technological changes, weakening of societal control, or lack of collective concern. There is a growing realization now that these time-tested values need preservation and fine-tuning while introducing new technologies and innovative ideas. To strike a balance, we have to revisit some technologies that helped the local inhabitants to survive and prosper for millennium in this harsh arid environment. Thar Desert has thousands of years of cultural heritage backed up by a wealth of traditional wisdom. Relevance of this Indigenous Technical Knowledge (ITK) needs to be understood in the present-day context and improved upon continuously. Willing participation of local communities and rural institutions from planning through execution in R&D efforts, therefore, assumes a high priority.

Developing a strong linkage with stakeholders: Sincere efforts during the last five decades by research institutions to develop appropriate technologies for sustainable development of arid areas and the efforts of the Government to promote many of the technologies under numerous development and relief programmes have contributed significantly to upliftment of the rural communities in the desert. Recent experiences suggest that a micro-farming approach within the defined agro-climatic zones can provide synergistic output from the available resources. However, successful execution of any programme from research to development requires effective linkage of the R&D institutions and SAUs with the government line departments, NGOs, and the stakeholders. People's participation has to be given high priority to develop suitable value chains for higher economic productivity.

In a fast emerging scenario of agri-business, bio-informatics, water productivity, globalization, WTO, and competitiveness, provisions have to be made in our research planning to meet these challenges and to convert the strengths into opportunities and reducing the weaknesses and threats into sustainability. Some of the key areas that need strengthening and interlinked for synergistic development of the region are as follows.

- Assessment and monitoring of natural resources, creation of digital database and development of land information system for area-based planning. These plans need to consider resource conservation areas, as well as alternate land uses.

- Desertification assessment and monitoring at periodic intervals, drought assessment in near-real time and a system for identification of areas vulnerable to drought, as well as early warning of drought need to be carried out, if needed in a network mode.
- Development, on priority, of sustainable and profitable farming systems (arable crops + horticultural crops + trees + shrubs + grasses + medicinal plants + livestock, etc.) and alternate land use strategies, suitable for the evolving socio-economic conditions, and within the broad framework of agro-climatic/land resources zones.
- Viable research methodologies for development of wastelands, which constitute ~30% of the arid zone, need to be developed, and implemented in village situations to demonstrate their potentials for employment and resource generation.
- Management of surface and ground water for efficient input utilization and integrated watershed management wherever possible. Harnessing multiple water productivity needs to be given high priority in canal command areas.
- Pressurized irrigation for efficient use of water and other inputs to conserve water needs a priority.
- Improvements in indigenous trees/shrubs/grasses/crops, as well as the underutilized plants, particularly for drought and pest resistance and early-growing traits, adopting conventional and biotechnological tools, need to be brought about at the earliest in a systematic manner.
- Conservation and improvement of indigenous livestock breeds and enhancing the productivity of livestock through feed, fodder and health management.
- Integration of livestock in farming system, their multiple use and value addition of livestock products should find priority.
- Maintenance and improvement of soil health adopting organic farming, improved nutrient availability and eco-friendly IPM techniques need to be developed.
- Design and development of efficient and low-cost tools and implements for various agricultural operations including tillage and post-harvest.
- Energy management (solar/wind), and utilization of the non-conventional, renewable energy resources, including the applications of nano-technology in photovoltaics, and finding potentials of hybrid fuel cells.
- Augmentation of post-harvest technology and value addition to minimize losses, generate employment and increase profitability. Avenues for market chains are to be explored and suggested for higher economic gains of grassroots producers and ultimate consumers through people's participation.
- Technology transfer, human resource development and capacity building need to be strengthened for rapid diffusion of technologies to stakeholders.
- Modalities for exchange and sharing of information, knowledge, expertise, experiences and technologies are to be improved to ensure that scientists and stakeholders are able to find viable solutions together.
- To accomplish the desired results Government Organizations (GOs), Non-Government Organizations (NGOs), stakeholders and financial institutions have to work in a consortium mode to upscale the factor productivity under the ongoing Government programmes.
- Appropriate policy interventions at national to local scales, and gender empowering are also required to foster sustainability, growth and equity in the region.

8. ISSUES

Agriculture often has a knife-edge relationship with the environment, with either too much intensification – or too little – for the sustainable use of natural resources. Much of the technical, institutional, and policy know-how exists to sustain productivity growth in both situations. Yet the fast-changing scenarios call for not only strengthening of research in agriculture, but also undertaking new researches, as well as wider dissemination of research output.

NATURAL RESOURCES MONITORING

Resource assessment

Arid zone of India is an area having poor and fragile resources as compared to the other wetter parts of the country. Despite this, historically it is one of the most thickly populated deserts of the world, and has an agriculture-dominated economy. In order to strike a balance between the natural resource availability and its utilization, people in the region had many traditional practices, the so called traditional wisdom, that put restrictions to unsustainable practices. However, burgeoning human and livestock populations during the post-independence era has forced people to exploit increasingly more from the land, bringing more of the marginal lands under the plough and exploiting higher amounts of scarce groundwater for cropping and other enterprises that are being strengthened by technologies and pace of modernization, especially during the last three decades. As a consequence, production from the land has increased, but at the cost of declining groundwater, accelerated soil erosion, water logging, salinization and other ill-effects on land that are forcing farmers to abandon cropping. Sooner or later this would lead to a decline in production and trigger complex societal problems. Hence land degradation needs to be minimized to stabilize productivity of these lands. Time has come to monitor the status of the dynamic land resources through repeat surveys and keep the information in usable database to suggest sustainable land management practices. Following are the suggested research focus:

- Systematic monitoring of natural resources at periodic interval
- Creation of resource database and resources planning for sustainable land management
- Quantification of plant biomass, soil carbon and carbon sequestration under different land use systems
- Environmental impact assessment for canal command areas, mining and industrial activities.

Area-based planning

In order to better understand the rapidly changing phenomena and to suggest area-based planning, assessment and monitoring of the resources would be continued at different time periods. Database on the natural and human resources, as well as climate would be quantified and kept in digital form under GIS, to enable the creation of a Land Resources Information System. Emphasis will be laid on quantification of the current and potential productions from the land, both under natural and stressed environments, so that information could be used to assess future requirements vis-à-vis resource availability and resource degradation. Also, the digital database can be accessed for planning at watershed, on index catchment or village cluster basis. The plans could be executed through participatory mode to enhance sustainable production from land-based activities. The quantified resource data will also be used for monitoring soil health to develop models for predicting degradation to take pro-active management measures for its reversal. Suggested research focus is on:

- Quantitative analysis of land use systems at higher integration levels
- Applications of systems approaches for regional land use planning and natural resource management at different scales
- Enhancement of GIS applications for agricultural land information on local to regional scales.

Desertification

High human and livestock pressures on the land have created problems of desertification. Research efforts will be strengthened to assess and monitor the desertification processes at higher spatial resolution, using remote sensing and GIS, and through basic studies on wind and water erosion for quantification of the processes. Application of simulation models to predict soil erosion will be tested to identify areas in need of pro-active measures for control. Impact of climate change on desertification processes will also require in-depth studies. Combating desertification is a global, regional and local issue. Impact of desertification control measures at local to regional levels is also to be monitored systematically. Working in collaboration with international and regional institutions will help to generate new ideas and techniques that could be implemented locally for harnessing maximum benefit. The issues may also be addressed by a network approach. Research focus is suggested on:

- Bench marks for indicators, assessment and monitoring of desertification
- Quantification of wind erosion under different land uses
- Quantification of water erosion process under different terrain conditions.

Drought

Studies have confirmed that despite technological developments, the region is vulnerable to drought, its impact varying from area to area, but it keeps crawling in and sometimes assumes the dimension of famine. Every year funds for drought relief are made available to alleviate the adverse impacts of partial or severe drought, and are utilized mostly for providing drinking water, food and fodder. However, a permanent drought coping mechanism is yet to be developed. Drought assessment and monitoring will continue to be researched for developing a better coping mechanism. The institute also wishes to participate in national/regional drought networks for mutual exchange of information. Efforts will be made to find out vulnerability of different areas of the region to drought, highlighting factors that are key to vulnerability. This might ultimately help in developing measures that would lead to better preparedness for drought. Based on meteorological studies, agricultural advisory will also be provided to the farmers. Also, blending the traditional mechanism of drought proofing with modern innovative interventions will be tried. It is felt that combating drought through up scaling of land-based activities on wastelands that constitute ~30% area of western Rajasthan, will provide permanent drought proofing in the region. Suggestive research focus is as follows:

- Drought monitoring, vulnerability and impact on policy interventions for community resilience
- Identification of drought hot-spots in arid fringes for likely spatial changes in arid boundaries
- Drought early warning system and impact analysis.

PLANT IMPROVEMENT

Plant biodiversity

Arid regions are endowed with large number of unique endemic plant species. This natural pool of adapted genes stands threatened due to large-scale over-exploitation and other human activities. Potential use of this rich biodiversity for the benefit of mankind needs further strengthening. In addition to domesticated plants there are many other species that have been used by the local inhabitants for various purposes and in the present context, have economic as well as ecological significance. It thus becomes imperative to survey and monitor this biodiversity, and conserve it for the future. This has become more important in the changed global scenario of IPRs and search for novel genes.

Arid ecosystems are fragile where plants respond to perturbations by their further degradation and consequent loss of variability. It is necessary not only to collect, conserve and catalogue the biodiversity, but also to map biodiversity richness and sparseness so as to delineate hot spots for protection, and to delineate biodiversity reserves for utilization by future generations.

Many of the indigenous plants adapted to harsh arid environment yield products of economic importance like gums, alkaloids, pigments, etc. To make the best use of biodiversity available with us, it will be imperative to identify and utilize active ingredients of economic and commercial value in desert flora. This will help in better utilization of our plant wealth and will not only help in generating employment in rural areas, but also add value to our products for higher income generation. Suggested research focus is on:

- Collection and preservation of genetic resources of trees, shrubs, grasses, and crops
- Evaluation of threat to the species.

Genetic improvement

Enhancing productivity of the dry regions is a priority area and adoption of improved cultivars can contribute enormously towards this goal. Low and erratic rainfall sets the limit on annuals in providing stability to arid agriculture. Improvement of trees, grasses and other perennials that provide sustainability to arid eco-system is thus necessary. Moreover, it may be possible to correct or replace a poor quality seed of arable crop easily, but inferior planted trees will continue to give poor yields for decades to come. There is therefore a need to introduce/conserve genetic biodiversity and improve both perennials and annuals to increase the overall productivity and profitability. There are many adapted plants of economic importance like henna, senna, guggal, kair, tumba (*Citrullus colocynthes*), etc., in the region. It will be necessary to collect their germplasm and initiate improvement programme on such plants on priority. This will not only help in crop diversification, but will also be useful to increase the total factor productivity and profitability from the region. Crops and cultivars requiring low inputs need to be identified.

Crops like pearl millet, clusterbean, mung bean and moth bean that are grown in dry areas, are more prone to abiotic stresses like drought and high temperature, and biotic stresses like pests and diseases, including nematodes and soil-borne pathogens like *Sclerospora, Fusarium* and *Macrophomina.* The local land races possess a high degree of resistance to these stresses. Steps are needed to collect, conserve and characterize such landraces and isolate and utilize specific genes responsible for stress tolerance.

In arid legumes, a few traits like indeterminate growth habit, high degree of flower shedding, longer vegetative, but shorter reproductive growth phases and poor partitioning of biomass need improvement. Mutation breeding provides good avenues for induction of these desired traits that may not be available in the existing germplasm. Besides, breeding of specific plant types suited to mixed and intercropping need to be given priority. Identification of molecular markers linked to specific traits like pollen fertility restoration, heat and drought tolerance, disease and pest resistance will also be undertaken to allow the marker-assisted rather than phenotype-based selection. Suggestive research focus is on:

- Genetic engineering and mechanisms of drought resistance
- Characterization of heat and salinity resistance of varieties
- Evaluation of crops for resistance to diseases and pests and development of breeding materials.

Molecular biology

Many of the plants lack distinct morphological markers and many important trees like Khejri (*P. cineraria*) have long life span. It is not only important to quantify the extent of variability, but also to understand the reproductive biology of such plants. This information is a prerequisite for developing any improvement or germplasm collection/conservation strategy. Biochemical and molecular markers can be effectively used to generate this information and identify markers linked to economically important traits.

Fluctuating environments and frequent droughts hamper selection and evaluation programmes and the assessment of response to stress and diseases are neither uniform nor adequate. Biotechnological approaches like use of quantitative trait loci can help screening and developing stress and disease resistant lines for crops like pearl millet. Combining breeding and biotechnological approaches can pyramid such genes. Suggested focus on research are:

- Elucidation of molecular mechanisms of abiotic stress tolerance and improvement of stress tolerance in important plants
- Utilization of molecular and biochemical markers for understanding genetic diversity and reproductive biology
- Mapping of quantitative trait loci and gene pyramiding for biotic and abiotic stresses.

Quality planting material

Timely and adequate availability of quality planting material is the first and the most important step towards increasing productivity of arid region. Aberrant weather sometimes results in failure of germination, requiring second or even third sowing. There is an urgent need to increase breeder seed production of crops like pearl millet, legumes, important forage species and other economically important plants. Looking to the climatic situation, arid region is more suited to seed production. Wherever water is available in canal, wells and watershed areas, the production of quality seeds of grasses, trees and other arable crops will be remunerative due to their advantage as disease-free seeds from a dry environment. Protocols for mass multiplication and vegetative propagation of many economically important and horticultural plants have been developed by CAZRI. These need to be effectively used for mass multiplication through collaborative efforts of R&D institutions and state/national seed producing agencies, with liberal support of financial institutions. There is also a nee to conduct research on nursery techniques, especially in case of vegetables and transplanted species for development of healthy planting material. Research focus is suggested for:

- Technology to produce quality seeds and planting material
- Micro-propagation of elite crops, grasses, shrubs and trees
- Studies on eco-physiology and gene-ecology of young plant material in nurseries
- Supplementary natural regeneration of economically important tree species.

CROP PRODUCTION STRATEGIES

The productivity of crops in arid region is low mainly due to low and erratic rainfall and due to soil and environmental constraints, including high temperature and poor soil physico-chemical and biological conditions. To keep pace with increasing population, suitable crops and their varieties need to be identified, managed and integrated in cropping systems that not only make the crop production sustainable, but also profitable. While introduction of canal and tubewell water has improved the crop production, it has also introduced second-generation problems, which need immediate attention. Suitable models of arable and integrated cropping systems need to be developed through on-station and on-farm research. Agro-techniques are available through limited and pressurized irrigation to economize on water use at least by 50%. Government-launched programmes are to be dovetailed to increase efficiency of input and thus enhancing production.

Crop production zones

In view of high competition and increasing demand, cultivation of high water-demanding crops is becoming more popular in arid region. This is becoming more harmful for natural resources conservation. Growing of well-adapted and low water-requiring crops should be made mandatory. In view of fast and easy transport facilities the best performing crops in a given agro-climatic zone should be grown. For example low water-requiring, high fodder-yielding, and soil-improving crops should find prominent place and preference in cropping system. Crop zones are to be delineated and refined at macro- and micro-levels in arid zone. Following are suggested for research focus:

- Meteorological and soil factors which cause instability in crop production
- Research network to improve production with international co-operation
- Environmental resources related to agricultural production and land use.

Precision farming

Nearly 60% of area of the country is rainfed. Enhancing production from these drylands will fulfil long-term needs of food and fodder security. Further, the productivity of dryland crops is very low as compared to the achievable potential. Therefore, even a marginal increase in factor productivity of rainfed crops will make considerable difference in total food grain production of the country.

Understanding physiological basis of low yields in dryland crops is to be further intensified. In the light of genetic and phenotypic expressions, increased photosynthate assimilation and their efficient distribution may result in quantum jump in crop yields. There is a need to optimally match the crop phenology with the availability of resources and environmental constraints like duration of growing period, availability of moisture, etc. Root growth and its distribution need to be studied in the context of moisture extraction pattern. There is an urgent need to develop physiological, biochemical and molecular markers to evaluate stress tolerance of crops and genotypes. Such indices/markers may help in rapid screening large number of breeding material for their stress tolerance. Intensified efforts are required to alleviate the adverse effects of stress on crop productivity through soil fertility, hormonal treatment and other crop management practices. Likewise, possibility of developing mid-season corrections/manipulations to stabilize yields in the event of monsoon failure needs to be explored. Based on water use, the crops requiring less water will be identified and effects of soil moisture deficits on water use and crop yields need to be quantified for different agro-climatic sub-zones.

Water is the key issue of arid zone. Therefore, vigorous efforts are required to enhance the use efficiency of water and nutrients. Maximization of area under life saving irrigation by use of drip and sprinkler needs top priority. Indiscriminate use of irrigation water has resulted in not only its wastage, but in water logging and soil salinization. Therefore, water is to be used judiciously. This can be achieved through adoption of sprinkler and drip irrigation systems. Research is needed to maximize the profitability, and to minimize the payback period. Likewise, under the extreme arid situations of Jaisalmer area, polyhouses and sustainable agro-techniques need to be developed for protected agriculture. Israeli method of agriculture needs consideration for growing high-value vegetables and fruits with limited water.

Due to beating effect of rain drop, surface crusts are formed that reduce the seedling emergence, leading to poor crop stand. Hence, developing techniques that minimize the crust formation, developing crust breaking tools and incorporation of soil conditioners that improve the retention of moisture in root zone will be essential for improving the crop growth and yield. Desert soils are poor in organic carbon and nutrients. So, possibility of incorporating composted crop residues and farm wastes need to be evaluated. Weeds aggressively compete with crops for nutrients, soil moisture and radiation. Therefore, effective weed control measures need to be developed. Possibility of using these weeds for incorporation in the soil as organic residues may also be explored. Efforts may also be made to utilize crop residues and farm wastes for cultivation of edible fungi for income generation and nutritional security in rural areas. Conservation tillage is to be re-emphasised in the light of residue management to maintain desired level of organic carbon and soil fertility. Such tillage systems may conserve soil, water and energy, and make crop production profitable. Developing optimum tillage systems for different soil conditions/ agroecological regions may go a long way in making farming in the region sustainable. Crop rotation, which improves soil fertility, should find prominent place in the cropping system. Due to low soil fertility the crops are unable to take advantage of favourable soil moisture during normal rainfall years. Addition of nutrients may improve the crop growth and yield. Work on integrated nutrient and pest management need to be intensified to reduce dependence on chemical fertilizers and pesticides. In view of the increasing demand for agricultural produces raised without chemicals, efforts on organic farming, particularly for high value crops, need to be intensified.

Cropping systems of a region are governed by market demand, soil conditions and climatic parameters. Farmers prefer pearl millet as it is an important grain crop and has excellent fodder value. In the event of crop failure due to drought this crop provides much-needed fodder to livestock. Therefore, pearl millet-based cropping systems need to be further refined to assure stability and sustainability. Studies need to be intensified on in-situ rainwater harvesting for improving productivity of kharif crops. In vertisols the raised broad beds and furrows have been effective in improving crop yields. These need to be evaluated under Aridisols, and effective implements be developed for such land configuration. Work on dual-purpose varieties is to be further strengthened. Similarly intercropping, mixed cropping of arid legumes and hitherto under-exploited medicinal plants need to be explored for crop diversification. Micro-meteorological studies on crops will be continued to better understand the relationship between climate variables, climate change and crop growth parameters, so that water budgeting for the crops is addressed in a better way through predictive crop-weather models. Suggested research focus is:

- Operational (decision support) systems for land use planning and analysis and their components
- Integrated pest management in farming systems
- Mitigating the effects of hydro-climatic extremes
- Regulation of tree form and nutrition quality of fruits.

Soil microbial diversity

Mobilization of nutrients from native unavailable soil pool to available pool through AM-fungi, phosphorus solubilizing bacteria and phosphatase producing fungi and mineralization of nutrients from farm residues/wastes may substantially improve the crop yields. Substantial work on biological nitrogen fixation and associated mobilization of soil phosphorus has been done in the past, but there is scope to push the yields of arid legumes through the use of biological nitrogen fixation at farmers' fields. Improved strains of soil microbes, tolerant to desiccation, should be identified so that availability of nutrients to crops is increased under stress conditions. Once identified, these adapted microbes need to be multiplied on mass scale for wider adoption amongst farmers. An active collaboration between research institutions and industries is called for to substitute chemical fertilizer by organic manures and bio-inoculants. At genetic levels, the genes in these microbes responsible to impart tolerance against drought, salinity and poor fertility, may be identified. Suggestied research focus, including integrated nutrient management, is:

- Improvement of the fertility of sandy soils through organic matter management
- Characterization and exploitation of biological nitrification inhibition
- Good soil care
- Evaluation of nutrient cycling in diversified cultivated ecosystems and soil amelioration
- Utilization of stress-tolerant and beneficial soil microbes like N-fixers, P-solubilizers and AMF for arid soils
- Identification of genetic markers for soil microbes for stress tolerance
- Integrated nutrient management for sustainable crop production
- Conservation tillage, weed management and recycling farm wastes for enhancing productivity and profitability.

Integrated pest management

The problem of disease and pest infestation is relatively less in dry regions. However, due to introduction of canal and well irrigation in last three decades the disease and pest scenario has drastically changed and new diseases as well as both vertebrate and invertebrate pests are emerging. Surveillance of important pests and diseases and studies on their biology and ecology need to be strengthened. More emphasis is to be given on isolation and identification of native biocontrol agents, their evaluation and mass multiplication for field application. There is also a need to strengthen research on identification and exploitation of plant products of pesticidal value and their formulation development. The work on inducing resistance in plants against economically important pests and diseases has so far not received due attention. More efforts are, therefore, needed to induce disease resistance in plants using conventional and biotechnological approaches. Following are the suggested research focus:

- Dynamics of insects, rodents, nematodes and pathogens in farming systems and development of IPM schedules
- System based forecasting models of diseases, pests and rodents
- Identification and multiplication of bio-control agents and bio-pesticides for insect pests
- Development of management techniques for soil borne diseases in hotspot areas.

LIVESTOCK PRODUCTION

This region is gifted with some of the best drought-hardy breeds of livestock such as Tharparkar, Nagauri, Shahiwal, Kankrej of cattle and Marwari sheep and Marwari and Parbatsar goat. Integration of livestock with farming system is of foremost importance and priority today. It also calls for cooperative movement for increasing milk and animal productivity, fodder production on priority, value addition of milk and animal products for profitability and their proper marketing. Many of these grey areas need public-private partnerships. Adequate planning is required for fodder and grazing lands to sustain animal wealth during adversities.

Small ruminants like goat and sheep fit better in low productivity grazing lands in arid region. Breed conservation, improvement and utilization are to be the priority areas to pursue, while physiological and biochemical studies are to be strengthened for adaptability vis-à-vis higher production. Further studies to evaluate suitable indicators for adaptation and production are contemplated. Due to inadequate nutrition, the genetic potential of these animals for productive traits is not expressed fully. Physico-chemical and probiotic treatments can help in enhancing the nutritive quality of local feedstuff. Extremes of climate affect the water requirement, rumen environment and certain physiological parameters of the animals. Efficiency of digestion/absorption of certain nutrients is also affected, and require in-depth studies. There is a need for increased and sustainable livestock production through improved genetic potential, feeding, health, animal and natural resource management, as well as development of appropriate post-harvest techniques for animal production.

Animal biodiversity

The breed characterization, and productive and reproductive performance of some desert livestock have been documented and work on genetic characterization of goat breeds has been initiated. Further work on genetic characterization of livestock breeds, development of systematic plan for breeding, propagation and conservation of indigenous hardy, disease-resistant and productive animals is to be taken up. The impact of introducing new livestock species and migration patterns of the livestock need also to be studied. Suggested focus on research is:

- Physiological characteristics of livestock and of prevalent animal diseases
- Livestock-land use-climate interrelations and interactions.

Feed and health management

A benchmark survey of management practices of livestock needs to be taken up. Housing of animals has been neglected due to various reasons. Proper animal housing can relieve the animals from climatic stress and divert the nutrients towards livestock produce. Hence, further studies on multipurpose shelters using locally available resources are needed to provide comfortable microenvironment to animals.

Infertility due to nutritional imbalance and deficiency is a major issue in livestock farming in the region. For evolving a package to improve the livestock fertility detailed studies on reproductive physiology and clinical studies on the causes of infertility are needed.

Physiological adaptation to heat and water stress has been documented in some sheep and goat breeds, and data on minimum feed and water requirements and productivity performance of livestock have been generated. In-depth studies are now needed on sustenance under climatic stress and nutrition disorders and measures to correct such disorders. Also, studies on energy, protein, vitamin and mineral requirements and their utilization, as well as possibilities of using problematic feed, and water containing harmful and injurious salts is to be studied and remedial measures evolved.

Feed and fodder security is a major challenge for rearing livestock in the region. Feed storage and fodder bank is an age-old practice here. Although fodder compression and feed-processing machines have been developed, appropriate methods for storage of forages need to be evolved. Though high livestock population is a strength here, low per capita productivity is a major weakness. Majority of desert livestock is range foraging. Detailed survey of floral composition, nutrient levels and digestibility of the forage is thus warranted. Nutritional constraints like lignin and tannins are also present in some desert feeds. Microbes with their specific capacity for degrading variety of components and chemicals have proved useful for delignification. Native microflora will be screened for such microbes. Strain development programme, including genetic manipulation, will be undertaken and techniques standardized for commercial use. As the rumen microfloral composition plays an important role in nutrition of livestock, microfloral changes under the influence of dietary composition and environmental stresses will also be studied.

Small-scale livestock product processing units and processes to enhance their shelf life is to be evolved. Studies on macro- and micro-mineral status of desert soil, water and forage will be strengthened, and relationship of minerals in soil-plant-animal continuum with clinical symptoms of deficiencies and imbalances in animals will be studied. With changing livestock scenario, livestock species proportionality, based on vegetation types and carrying capacity of the land will be re-established. There is a need to monitor pasturelands and their improvement adopting modern techniques. Sustainable livestock production is possible through cultivation and improvement of pastures by the farmers. This needs some policy decisions and subsidies to encourage the growing of forage crops.

Since buffalo population is increasing at a fast rate, particularly in irrigated areas, studies on population dynamics of buffalo breeds, their adaptability, management, health, reproduction and milk production will be necessary. The suitability of stall-feeding outside the irrigated areas, and under limited availability of fodder and drinking water, needs evaluation.

The average fish production from natural reservoirs in Rajasthan varies from 10 to 14 q ha^{-1}, but in some areas, particularly in medium-sized irrigation reservoirs, even 100 q ha^{-1} fish harvest is reported. For nutritional security of desert dwellers and income generation, brackish-water fish culture can be experimented in areas having such groundwater that is otherwise unfit for cropping.

Similarly, poultry production, a common practice in semi-arid regions, has a good potential as a backyard practice for improving nutrition and income generation. It should include better management practices, including housing under extremes of climate. Suggested focus on research is:

- Local forage resources and development of sustainable agro-pastoral systems
- Livestock-plant interaction with emphasis on nutritional disorders and developing corrective measures through supplements
- Conservation, value addition of fodder/feed and minerals in livestock production, health and diseases
- Studies on adaptability of buffalo, and its management practices for rearing in command and non-command areas.

Livestock in farming systems

Despite the fact that livestock is an important component of farming systems in the region, most of the animal studies have been carried out in isolation. Presently the livestock-based farming is experiencing fast changes, due to which the number and types of animals being reared are changing, and the migration pattern is feeling the crunch of shrinking pastures. Hence there is an urgent need to study the impacts of such shifts and also to optimize the proportion of livestock in different farming systems for maximizing the profit. Following are the suggested research focus:

- Conservation of native breeds through distribution of pedigreed bulls, artificial insemination, etc., and monitoring of the improvement in collaboration with state animal husbandry departments
- Development of prediction models for fodder availability and requirement in relation to climatic aberrations, including contingency planning for fodder based production systems
- Studies on livestock-based small farming systems, value addition of livestock products and cooperative movement for marketing in public-private partnership mode for maximization of benefits
- Development of sustainable fodder bank and multipurpose shelters
- Harvested runoff based environment-friendly methods of aquaculture and other organisms.

INTEGRATED FARMING SYSTEMS AND WATER MAMAGEMENT

A territorial approach to rural development calls for localized agro-rural production systems, where farm and firms in extended agriculture interact in clusters of economic activities, with cross-farm and cross-firm spill-over, enhancing the competitiveness of members of the cluster. Projects to support territorial development (region-driven development projects) need to be explored, patterned on the successful community-driven development approach to delivering public goods at the community level. Experimentation and impact analysis are needed to learn how best to design them. To do this, smallholder farming needs to be diversified and intensified by transiting into high value activities and green revolution techniques for lagging areas. With continuing population pressures in rural areas, agriculture alone will not reduce the income gaps, hence the need for vibrant local economies centered on secondary towns. Smallholder farming diversification into labour-intensive high value agriculture and extending the green revolution to areas where it has not yet reached, and rural off-farm employment in secondary towns through agricultural clusters, infrastructure investments, improved local investment climates, and rural-urban linkages need promotion.

Integrated farming systems

To support burgeoning population of human and animals, integration of different components is required to impart sustainability to low productivity of crops and animals under harsh arid conditions. Farming system is an applied concept to help farmers/stakeholders with some backup research support to make them more productive and profitable. A small farmer survives when he has around him production systems providing food, milk and animal fodder, a resource to sustain animals, some fruits and vegetables and some source of income to support livelihood. These factors of production need to be converted into more efficient synergistic and complementary to each other, through recycling of by-products and ending up in a value added chain for efficient marketing through partnership. Weaker links of this chain should be strengthened to harness maximum output. Productivity of existing cropping systems needs to be enhanced besides developing more productive alternate land use systems. To realise this, models of arable and integrated farming systems for sustainable productivity and resource conservation in the region need to be developed through on-station and on-farm research and popularization through a consortium approach.

This will involve evaluation of existing farming systems as the inhabitants have developed unique and location-specific farming systems like integration of khejri, khadin, etc. As livestock is an integral component of the farming systems, emphasis will be required on systematic studies for development of livestock-based small farming system models. At present there is very limited choice of trees, crops and grasses for the systems. Native as well as exotic species should be explored to widen the choice. There is a need to integrate other economic and medicinal plants in the farming systems. The diversified agriculture will provide sustainability and may be useful from both economic and ecological angles. Fruit trees, grasses and other perennials are known to impart sustainability in arid regions. Efforts are required to develop alternate land uses, especially agroforestry, silvo-pasture systems and horticulture-based farming for different agro-ecological situations in the region. Greater understanding of tree-crop interactions is required to develop such models. Suggested research focus is on:

- Livestock/horticulture-based diversified farming systems
- Development of agro-forestry and silvo-pasture models
- Livestock-based farming systems with emphasis on sustainable pasture with multiple productivity of diversified agriculture, including horticulture, medicinal and aromatic plants for different land holding sizes (small and medium farmers)
- Utilization of non-arable land for plantation of bio-fuel and oil-bearing crops for improved livelihood
- Farming systems for canal command areas
- Gardens/ avenues of gum and others production.

Water management

Water is the key issue and centre of activity in arid zone. Therefore, all out efforts should be made to conserve rainfall where it falls, through tillage, mulching, contour cultivation, etc., and through inter-row and inter-plot water harvesting. Excess runoff should be harvested and stored in structures like nadi, khadin, tanka, talabs, etc. Traditional wisdom existing in this regard is to be supplemented with novel innovations for increasing utility of such structures. The existing soil and water conservation measures, e.g., bunding, contour cultivation, terracing, etc., are expensive and in many situations difficult to maintain. Farmers need simple, economically viable and easily implementable productive practices. With the growing interest in the protection of environment, vegetative measures of soil and water conservation, such as bund strengthened by vegetative measures or even vegetative barriers need popularization. Arid areas are prone to excessive wind erosion. Therefore, various plant species that can conserve land and also provide economic returns to the community should be utilized as vegetative barriers.

Low and erratic rainfall, poor groundwater resources and increasing demand of water have stressed the existing water resources beyond repair. Frequent droughts and rare flash floods make it imperative to generate data on long-term averages of water and sediment balance. Conservation and storage of excess water generated in a flood year may alleviate the water scarcity situation in drought years. Develop and mandate strategies to recharge groundwater through urban runoff, flash floods and transferring the volume of water from surplus to deficient areas. Besides suitable rainwater harvesting for surface storages in many situations, artificial recharge of groundwater may be adopted to rejuvenate depleted aquifers. Research on various aspects of arid zone hydrology is also to be strengthened.

The changing cropping patterns, introduction of new crops, indiscriminate use of water through canal systems or through pumping of ground water have necessitated working out the water budget and water productivity of different crops and cropping systems. Suggested research focus is on:

- Integrated watershed management for livelihood generation and ground water recharge
- Utilization of waterlogged area and stored water for multiple water productivity
- In-situ moisture conservation, rainwater harvesting for khadin etc. based production systems with multiple water productivity
- Management and utilization of saline water, sewage and industrial effluents for edible or non-edible biomass production
- Exploring multiple use of water to maximize production with this scarce commodity in arid zone

Management of degraded lands

Degraded wastelands constitute nearly 30% of geographical area of arid western Rajasthan. Management of these lands has always been a matter of serious concern and needs to be addressed on priority. Management of sand dunes and degraded lands entails reducing the hazards of soil erosion through plantation of trees/shrubs/grasses, shelterbelts and windbreaks, rangeland management and pasture development. Rocky lands can be utilized for fuel wood plantation. Saline/sodic lands can be utilized with adoption of suitable soil profile amendment and crop management and also efficient bio-drainage. There is a need to explore native tree/shrub species, which are useful for conservation/improvement of resources and also possess economic and social values. Uncontrolled mining activity is increasing at a fast pace, leaving a vast stretch of degraded land. Institute has already carried out rehabilitation of such mined wastelands. Use of suitable rainwater management technology along with use of polymers/organics, including microbial inoculants for quick and efficient afforestation of such degraded lands, needs strengthening. Suggestive research focus is:

- Evaluation of carrying capacity in changing scenario of degraded rangelands for different agroclimatic regions

- Sand dune stabilization studies through newer vegetative means in conjunction with mechanical and chemical methods including by-products of petroleum industry to make the system more stable on participatory mode
- Community based rehabilitation technologies for individual owned sand dunes, rangelands and mine wastelands
- Management of salt-affected areas and Banni grasslands.

FARM MACHINERY AND ENERGY MANAGEMENT

Post-harvest technology and value addition

The resource-poor farmers in arid region do not have access to electricity-based facilities for storage of agriculture produce, which results in spoilage of perishable products, causing immense financial loss. There is a need to extend the shelf life of ber and other perishable fruits and vegetables and animal products. Of late ber cultivation has spread to large areas and is now expanding into peninsular region. However, farmers are experiencing a major bottleneck in marketing ber due to its short shelf life. Therefore, research is needed to develop low-cost technologies, which could be used to enhance the shelf life of fruits, vegetables, milk and its byproducts. Further, to enhance the farm profitability value-added processed food products such as cheese from goat milk, and jam and squash from ber and other arid fruits are to be marketed for higher income to farmers. Rapid dehydration of farm produce that retains its colour, flavour and texture, may enable farmer to accrue higher profits. Considering the importance of PHT and value addition there is a need to develop and standardize equipment/machines/processes for farm produces, especially spices and condiments and horticultural produces. Following research focus is suggested:

- Value addition to agricultural products, horticulture, livestock, medicinal plants etc.
- Improving shelf life of perishables.

Value added chain/public-private entrepreneurship

For market-driven research and development a strong public-private partnership mechanism is to be developed that will harness full benefits of value-added chains to farming community. Suggested research focus is as follows:

- Mechanisms for developing systems methodologies: Interaction and exchange of information among multi-disciplinary research teams and stakeholders
- Developing an impact assessment model and formulation of a food supply stabilization plan.

Solar appliances

Plenty of solar radiation is available in arid region (ca. 6 kWh sq.m^{-1}) and this needs to be harnessed and gainfully utilized. Large number of solar-based devices like water heater, food and feed cooker, dryer, etc., have been designed and developed. Researches are now required to reduce their fabrication and maintenance costs, and to make them user-friendly. There is a need to develop efficient non-conventional energy systems based on new materials and design for different uses in household, agriculture, cottage industries and community. There is also a need to study application of new and emerging photovoltaic devices for arid region, development of compact, portable efficient integrated solar devices, improved solar thermal systems with alternate materials, large-size improved cool chambers and greenhouses for protected cultivation incorporating new technologies. Suggested research focus is:

- Design and development of integrated multipurpose solar devices
- PV-based micro-irrigation system for arid zone farming
- Evaluation of solar cells and auxiliary power system.

Farm equipments and tools

The sandy soils prevalent in the region have low water holding capacity, consequently a farmer has to perform field operations including sowing in the shortest possible time particularly during kharif to utilize available moisture and covering maximum area. Thus, conservation of moisture, both before and after sowing, is important for success of kharif crops. Conventionally, the crops in the region are sown on flat surface with little scope to conserve rainwater. Crop failure due to moisture stress owing to non-occurrence of rains immediately after crop sowing or long dry spell is a common phenomenon. There is also a problem of crust formation. As a result farmer is compelled to re-sow the crops. Ridge and furrow system of planting seems to be a viable option. Sowing of crops on slanting surfaces of a furrow may help conserve rainwater in the furrow, thus creating high moisture in the planting zone. It may also help to over come the problem of crust formation. Therefore, there is a need to design and develop tractor operated multi-crop sowing device for such conditions.

Considering high livestock population in the region complete package of tools, implements and machines is to be developed for cultivating grasses and fodder. For proper storage, conservation and transportation of fodder, its densification is essential. In this context, feed blocks are suitable to supplement the forage and crop residues with fortification of nutrients, protein, energy and minerals. Therefore, animal feed block-making machines, bailers, compacting and pelleting machines need to be developed. Suggested research focus is on:

- Development of efficient seeding devices
- Development of farmer-friendly harvesting tools
- Development of efficient devices for cultural operations
- Design and development of cool chambers and polyhouses.

TECHNOLOGY DISSEMINATION, CAPACITY BUILDING AND IMPACT ANALYSIS

A " new agriculture" has emerged, side by side with the old agriculture of basic food and traditional producers, offering good investment options based on emerging markets and innovations. The "new agriculture" is market-driven, state-assisted, and civil society-influenced. Private entrepreneurs in extended value chains lead it. It makes extensive use of technological and institutional innovations in flexibly capturing dynamic market opportunities. This new agriculture, which includes many entrepreneurial smallholders, competes with and influences the old agriculture of staple foods and traditional smallholders, transforming it toward greater market integration and meeting more differentiated consumer demands. The welfare effects of these major changes will depend on the extent to which the rural poor are able to capture direct benefits as producers and indirect benefits as workers and consumers of food. The outcome may have major growth effects for countries where agriculture is the main economic sector and major welfare effects on the lives of millions of smallholders and rural poor. Even now the impact of climate change, the looming water crisis, the slow adoption of new biotechnologies, and the demand for bio-fuels create considerable uncertainty about the future global food situation. The high share of labour in agriculture and low share of agriculture in GDP typify the income lags between rural and urban areas – lags that translate into excess poverty in rural areas and mounting political pressures for compensatory measures. We should look agriculture as an instrument for "sustainable pro-poor growth", "agriculture" as crops, livestock, agro-forestry, and aquaculture, "extended agriculture" as encompassing the food, feed, fiber and energy system and " development" as income growth, reduced poverty and vulnerability for all, including women, and sustainability in using natural resources and providing environmental services.

Socio-economics

Socio-economic investigations provide an understanding of livelihood in the arid zone. It is necessary to understand the food and nutritional status and needs of people in the region. Concerted research efforts are also needed on socio-economic analysis of livestock/land distribution, standardizing socio-economic variables for desertification modelling and cost of land degradation and cultivation.

People of the region in their effort to survive in adverse conditions have developed numerous ITKs. These need to be identified and catalogued, validated, refined and popularized in relevant areas. Due to resource constraints the level of education among inhabitants is low, particularly among the girls. Likewise there are other social and cultural issues related to gender bias. There is a need to understand and address these issues in right perspective for empowerment of woman.

A large number of technologies for sustainable development have become available through multidisciplinary research at CAZRI. Only a few of the technologies on arable and perennial crops have found favour with farmers. There is a need to further strengthen the research in the areas encompassing all the facets of on-farm production and consumption. It will involve identification of shortcomings of technology through on-farm research, market linkage studies of major crops grown in the region, employment and income generation aspects of alternate land use systems, and prospects of value addition in the existing or alternate cropping systems.

The issues related to farmwomen need greater focus considering their role and responsibilities in farming systems. Conceptually, women empowerment entails two components: (a) social, economic, cultural political and educational empowerment; and (b) improvement in work efficiency and reduction in drudgery by supplementing mechanical work simplification tools, ergonomically designed drudgery-reducing tools.

The means to achieve these goals may be entrepreneurship development through agro-based market-efficient micro-enterprises, which pave the way for women empowerment by which essentially money changes hands, thereby ensuring greater control over resources and decisions. Following are suggested as research focus:

- Socio-economic monitoring and impact assessment of market, credit flow and development strategies for arid farming community
- Gender issues and women empowerment through income generation
- Using climate knowledge in designing conventional and non-conventional agricultural insurance systems

- Identification of product export zones.

Women empowerment and people's participation

A multidisciplinary team has to interact with farmers in different agro-climatic situations and find out research gaps as per actual needs of the farmers. These researchable issues have to be prioritized and then work initiated to find solutions. This will have better adoption rate and directly benefit the farmers. Technologies generated needs to be economically evaluated. Economic evaluation of technologies has to be conducted in real farmers' situation for wider adoption.

The existing farming systems are required to be thoroughly studied. Input-output relationships have been analysed for different components. An assessment is to be made as to what extent this relationship can be improved (in terms of output) by applying the research recommendations. A balancing exercise will be carried out between resource conditions and farmers' socio-economic conditions/priorities for selection of appropriate technological options. Over-emphasis of either of these two issues should be avoided. Farmers will be the equal partners in programme planning and implementation. The Issues related to farmwomen need greater focus, considering their role and responsibilities in arid land farming systems.

Focus would be on integration of various components: dryland farming, animal husbandry, amelioration of degraded lands, CPRs and appropriate utilization of limited groundwater resources (wherever possible) for irrigation. Value addition through post-harvest technology, introduction of economic/medicinal plants, hi-tech means, etc., will be promoted. Enhancement of forage resources will be a priority issue to bridge the gap between supply and demand for upgrading livestock productivity. Some suggestive mechanisms are -

- Getting the price incentives right
- Increasing and improving public investment
- Getting the markets right
- Improving access to financial services
- Promoting institutional innovations in science and technology
- Empowering farmers
- Making agriculture sustainable.

Agri-business

In the changed global scenario the markets are shrinking and global markets are influencing the local production, which in turn is influencing the farmer's economy. Hence, there is a need to understand various issues related to global and local marketing and communicate these to the farmers for effective economic gains. One of the primary factors influencing use of inputs for increasing productivity has been poor financial status of the people of the region. Hence, understanding of issues related to credit flow and other strategies for helping the farmer community are necessary.

Rich and varied livestock wealth of this region has not been fully utilized. Per unit area production continues to be low due to various factors including weak market linkages. Physiological and nutritional aspects of animals like sheep and goats have been the main areas of research so far. Cattle and buffalo also need equal attention considering their growing number in the region.

Documentation and analysis of processing, storage and market infrastructure for livestock produce are the other researchable issues that need to be pursued. Suggested research focus is:

- World food supply and demand and collaborative research strategy
- Intro and retrospective analysis for research strategy building
- Stable food supply systems for mitigating the fluctuations in production and markets
- Impact analyses of economic integration on agriculture and policy formulation towards alleviation of rural poverty.

Technology dissemination

Coordination among research, training and development sectors is most crucial to technology transfer and adoption by the farmers. This has been a weak link in technology transfer. A sound coordination system with built-in-accountability needs to be developed.

Technology demonstration and people's participation have become primary preoccupations within development efforts. Such initiatives would be more effective if people have required level of knowledge and positive attitude to analyse the benefits of technology. Technical know-how is therefore essential. Strong training and media unit can help reaching this objective.

Small holders in arid zone require more critical knowledge because their risk-bearing capacity is low. Socio-economic and agro-climatic conditions are also not favourable. Adequate communication support is thus a circumstantial requirement. This will require proper coordination between technologists and extension personnel. Different categories of developmental personnel need different types of training, i.e. vocational, popular, specialized, etc.

To carry out these tasks effectively, the communication, documentation and training infrastructures need a great deal of strengthening in terms of scientific and technical manpower and modern facilities/equipments. Feedback is integral part to any programme/activity for desired improvement in course of implementation. Periodic evaluation of programmes/activities provides feedback to policy makers, programme designers and executors for desired improvement. There could be a number of ingredients that are not observed in the initial stage of the programme and appear only during the course of implementation. Feedback analysis is thus essential for development of appropriate training strategies, including refinement of training content and methodology based on changing needs and job requirements, as well as for redesigning of media-mix. Suggested research focus is on:

- Developing technology assessment methods to determine factors that influence faster track technology diffusion
- Capacity building for improved livelihoods and watershed protection including environment
- Integrated rural resource management through satellite links of village resource centre
- Inventorization of ITK and assessment
- Agro-advisory based on weather forecasting.

AGRICULTURE-BASED LIVELIHOOD

Erosion of natural resources is adversely affecting livelihood like overgrazing in the pastures; water crisis due to high growth of humans and livestock; and recurrent droughts. Keeping livestock beyond carrying capacity many-a-times is resulting in low productivity. Shortage of timber has invariably affected the handicrafts. The distress response is migration. The livelihood solutions in the natural resource management sector surrounds on the pasture development and water conservations in the desert districts. The breed and productivity upgradtion is important in livestock. Intervention on marketing, designs etc. is the avenue for improving handicrafts. Eco-tourism may improve services, transport, etc. Services also need to reverse the migration of labour force. This is basically a human problem requiring human resource development, institutional support, physical infrastructure spreading and financial rapport. Some cross-cutting solutions are presented in Table 11.

Table 11.Cross cutting solutions

Sector	Human development	Institutional development	Physical infrastructure development	Inclusive financial services
		Rural Farm		
Agriculture	Agriculture skills	Farmers' Coops PACS	Irrigation, Power Markets	Credit Crop insurance
Animal Husbandry	Veterinary skills	Livestock breeders' associations	Fodder banks, Animal insurance Markets	Credit Livestock Insurance
Forestry	Forestry skills	Joint forest management committees Tree growers' coops	Nurseries Markets	Savings, Long term credit Health insurance
		Rural Non-farm		
Agro-processing	Sorting/grading skills Mechanical skills	Commodity coops (dairy, oilseeds, etc.) need revival	Power Warehouses Market yards Decentralized procurement	Savings Long term credit Health Insurance
Handicrafts	Updating skills for new markets	Artisans' associations/ cooperatives	Roads Power Prospecting	Savings Health insurance
Mining and Quarrying	Mechanical skills	Mineworker associations	Roads Power Prospecting	Savings Health insurance

Rajasthan Aajeevika Anveshan, with the help of RMoL-BASIX, is undertaking commendable work in this sector. Among various components, CAZRI is involved in rainfed agriculture, animal husbandry, agro-processing, self-help groups, micro-enterprises, etc., in creating job opportunities to the agriculture-based livelihood promotion. The policy support research in sustaining the benefits is need of the hour in view of fast emerging Special Export Zones and Contract Farming in the background of globalization.

The main function of agriculture is to create business opportunities in the new agriculture, delivering not only profits but also social benefits and resource saving in favoured regions. Getting the business side of agriculture to perform is thus an important part of the strategy (dynamic sub-sectors with comparative advantage such as high value crops, livestock, and biofuels, with favourable investment climates). Social benefits are derived directly from participation in these dynamic sectors and employment in formalized labour markets. Agriculture also has to reduce poverty in geographical pockets with agricultural potential. Marginal regions without agricultural potential may have to transit out of agriculture and provide environmental services. Productivity has to be increased beyond subsistence agriculture and non-sustainable holdings may have to be merged for viability or to be given over to other functions, with extensive reliance on pluriactivity. Insufficient progress on these issues will constrain us in implementing the agriculture-for-development agenda. The cost of inaction on many issues is now high, especially for mitigation and adaptation to climate change. Investing massively in human capital to support population transitions out of agriculture towards decentralized clusters of economic activity may be one solution to increase viability of agricultural sector.

9. PROGRAMMES

The proposed research activities under different programmes, as emerged from discussions in previous chapters, are summarized in Table 12, with priority settings in different time periods.

Table 12. Research activities proposed during the period

Program	Theme	Activity	Priority			Mode
			2007-2012	2012-2017	2017-2025	
NATURAL RESOURCES MONITORING	Resource Assessment	Periodic monitoring of natural resources	***	***	***	S
		Creation of resource database for resource planning for sustainable land management	***	***	***	S
		Quantification of plant biomass, soil carbon and carbon sequestration under different land use systems	**	**	*	A
		Environmental impact assessment for command areas, mining, industrial activities and oil exploration	**	*	**	S
		Digital mapping – capability enhancement	*	*	*	S
	Area-based Planning	Quantitative analysis of land use systems at higher integration levels	*	*	**	S
		Applications of systems approaches for eco-regional land use planning and natural resource management at different scales	*	**	*	S
	Desertification	Assessment, monitoring and bench marking of indicators	***	***	***	S
		Quantification of wind erosion under different land uses and modelling	**	**	**	B
		Quantification of water erosion process under different terrain conditions	**	**	**	B
	Drought	Drought monitoring, vulnerability and impact on policy interventions for community resilience	***	***	***	S
		Identification of drought hot spots	*	*	*	A
		Drought early warning system - Impact analysis for improvements	*	*	*	A
PLANT IMPROVEMENT	Genetic Improvement	Plant biodiversity: Collection and preservation of genetic resources of trees, shrubs, grasses, and crops	**	**	***	S
		Genetic engineering and mechanisms of drought resistance	***	**	**	B
		Characterization of heat and salinity resistance of varieties	**	**	*	S

		Evaluation of crops for resistance to diseases and pests and development of breeding materials	*	*	*	A
	Molecular Biology	Molecular analysis of resistance mechanisms	**	**	*	B
		Elucidation of molecular mechanism of abiotic stress tolerance and improvement of stress tolerance in model plants	***	**	*	B
		Utilization of molecular and biochemical markers for understanding genetic diversity and reproductive biology	*	*	*	S
		Mapping of quantitative trait loci and gene pyramiding for biotic and abiotic stresses	*	*	*	A
	Quality Planting Material	Technology to produce quality seeds and planting material	*	*	*	A
		Micro-propagation of elite crops, grasses, shrubs and trees	**	*	*	A
		Studies on eco-physiology and gene-ecology in nurseries of young plant material	***	***	**	S
		Supplementary natural regeneration of economically important tree species	**	*	*	A
ARID LAND CROPPING	Crop Production Zones	Meteorological and soil factors which cause instability in crop production	**	**	**	B
		Research network to stablilize production with international co-operation	*	*	**	A
		Environmental resources related to agricultural production and land use	**	**	***	S
	Precision Farming	Operational (decision support) systems for land use planning and analysis and their components	***	***	**	A
		Integrated pest management in farming systems including weeds	***	**	**	A
		Mitigating the effects of hydro-climatic extremes	**	**	**	S
		Regulation of tree form and eating quality of fruits	**	**	**	S
	Soil Microbial Diversity	Improvement of the fertility of sandy soils through organic matter management	***	***	**	S
		Characterization and exploitation of biological nitrification inhibition	**	**	*	A
		Good soil care (GSC)	***	***	***	S
		Evaluation of nutrient cycling in diversified cultivated ecosystems and soil amelioration	***	***	**	B
	Drought Physiology and Agro-	Physiological basis of abiotic stress tolerance, plant water relations, C assimilation and root growth pattern	***	***	**	B

	techniques	Modelling Crop micrometeorology for optimisation of multi-tier canopy system	*	**	**	S
		Enhancing water and nutrient use efficiency for sustainable crop production	**	**	**	S
		Development of agro-techniques for pressurized irrigation, organic farming for enhancing input use efficiency	***	***	**	A
	Integrated Nutrient Managemen t and Microflora for Improving Productivity	Utilization of stress tolerant and beneficial soil microbes like N-fixers, P-solubilizers, AMF for arid soils	***	***	**	S
		Identification of genetic markers for soil microbes for stress tolerance	**	**	**	B
		Integrated nutrient management for sustainable crop production	***	***	**	S
		Conservation tillage, weed management and recycling farm wastes for enhancing productivity and profitability	**	**	**	S
LIVESTOCK PRODUCTION	Animal Biodiversity	Genetic characteristics of arid livestock breeds and knowledge of prevalent animal management systems, status of productivity and health	***	***	***	A
		Livestock- land use -climate interrelations	**	**	**	S
	Feed and Health Manage-ment	Local forage and feed resources and development of sustainable agri-pastoral systems	**	**	**	A
		Livestock-plant interaction with emphasis on nutritional disorders and developing corrective measures through supplements	***	***	***	B
		Conservation, nutritional enrichment of fodder/feed and minerals in livestock production, health and diseases	***	***	***	A
		Studies on adaptability of buffalo, its management practices for rearing in command and non-command areas	**	**	**	B
	Livestock in Farming System	Conservation of native breeds through distribution of pedigreed bulls, artificial insemination, etc., and monitoring of the improvement in collaboration with state animal husbandry departments	**	**	**	A
		Development of prediction models for fodder availability and requirement in relation to climatic aberrations, including contingency planning for fodder-based production systems	**	**	**	B
		Studies on livestock-based small farming systems, value addition of livestock products and cooperative movement for marketing. public-private partnership mode for maximization of benefits	***	***	***	S

		Development of sustainable fodder bank and multipurpose shelter	***	***	***	A
		Harvested runoff-based environment-friendly methods of aquaculture for organisms	**	**	**	S
INTEGRATED FARMING SYSTEMS	Alternate Landuse Systems	Livestock/horticulture-based diversified farming systems for different land holding sizes (small and medium farmers)	***	***	**	B
		Development of agro-forestry and silvo-pasture models	***	***	***	B
		Livestock-based small farming systems with emphasis on sustainable pasture with multiple productivity of diversified agriculture including horticulture, medicinal and aromatic plants for different land holding sizes (small & medium farmers)	**	**	**	S
		Farming systems for command areas	**	**	**	S
		Gardens/avenues of gum and others production	***	**	*	B
	Water Manage-ment	Integrated watershed management for livelihood generation and ground water recharge	***	***	***	A
		Utilization of waterlogged area and stored water for multiple water productivity	***	***	***	A
		In-situ moisture conservation, rainwater harvesting for khadin etc., based production systems with multiple water productivity	***	***	***	A
		Management and utilization of saline water, sewage and industrial effluents for edible or non-edible biomass production	**	**	***	S
		Exploring multiple use of water to maximize production with this scarce commodity in arid zone	**	**	**	B
	Integrated Pest Manage-ment (IPM)	Dynamics of insects, rodents, nematodes and pathogens in farming systems and development of IPM schedules	*	*	**	A
		System-based forecasting models of diseases, pests and rodents	**	*	*	A
		Identification and multiplication of bio-control agents and bio-pesticides for invasive insect pests	*	*	*	A
		Development of management techniques for soil borne diseases in hot spot areas	*	*	*	A
	Manage-ment of Degraded	Evaluation of carrying capacity in changing scenario of degraded rangelands for different agro-climatic zones	**	**	**	S

	Lands	Sand dune stabilization studies through new vegetative means in conjunction with mechanical and chemical methods including by-products of petroleum industry to make the system more stable on participatory mode	***	***	**	A
		Community based rehabilitation technologies for individual owned sand dunes, rangelands and mine wastelands	**	**	**	S
		Management of salt-affected areas and Banni grasslands	**	**	*	S
FARM MACHINERY AND ENERGY MANAGEMENT	Farm Machinery	Development of efficient seeding devices	***	**	*	A
		Development of farmer-friendly harvesting tools	*	**	***	A
		Development of efficient devices for cultural operations	**	***	**	A
		Design and development of cool chambers and polyhouses	*	**	***	S
	Solar & Renewable Energy	Design and development of integrated and multipurpose solar devices	***	**	**	S
		PV-based micro-irrigation system for arid zone farming	*	**	**	S
		Evaluation of solar cells and auxiliary power system	**	***	**	S
	Post-harvest Technology and Value Addition	Value addition to agricultural products, horticulture, livestock, medicinal plants, etc.	**	***	**	A
		Improving shelf life of perishables	*	**	**	A
		Development of machines for densification of feed block	**	***	***	A
SOCIO-ECONOMICS	Agri-Business	World food supply and demand and collaborative research strategy	*	*	*	A
		Introspective and retrospective analysis for research strategy building	**	**	**	B
		Stable food supply systems for mitigating the fluctuations in production and markets	**	**	**	S
		Impact analyses of economic integration on agriculture and policy formulation towards alleviation of rural poverty	***	***	***	S
	Value Added Chain/ Public-Private Entrepreneurship	Mechanisms for developing systems methodologies: Interaction and exchange of information among multi-disciplinary research teams and stakeholders	*	**	**	S
		Developing an impact assessment model and formulation of a food supply stabilization plan	*	**	**	B
	Technology Dissemination	Developing technology assessment methods to determine factors that influence faster track technology diffusion	**	**	**	S

		Capacity building for improved livelihoods and watershed protection including environment	***	***	***	S
		Integrated rural resource management through satellite links of village resource centre	*	*	*	A
		Inventorization of ITK and assessment	**	*	*	S
	Socio-Economic Monitoring, and Impact Assessment	Econo-climate change based crop forecasting methodology improvement	*	*	**	A
		Socio-economic monitoring and impact assessment of market, credit flow and development strategies for arid farming community	**	***	**	S
		Gender issues and women empowerment through income generation	***	***	**	S
		Using climate knowledge in designing conventional and non-conventional agricultural insurance systems	*	**	*	A
		Identification of product export zones	*	*	**	A

Priority: Low: *; Medium: **; High: ***; Mode: Basic (B); Anticipatory (A); Strategic (S).

Linkages between the different activities are shown in a flow diagram (Fig. 21).

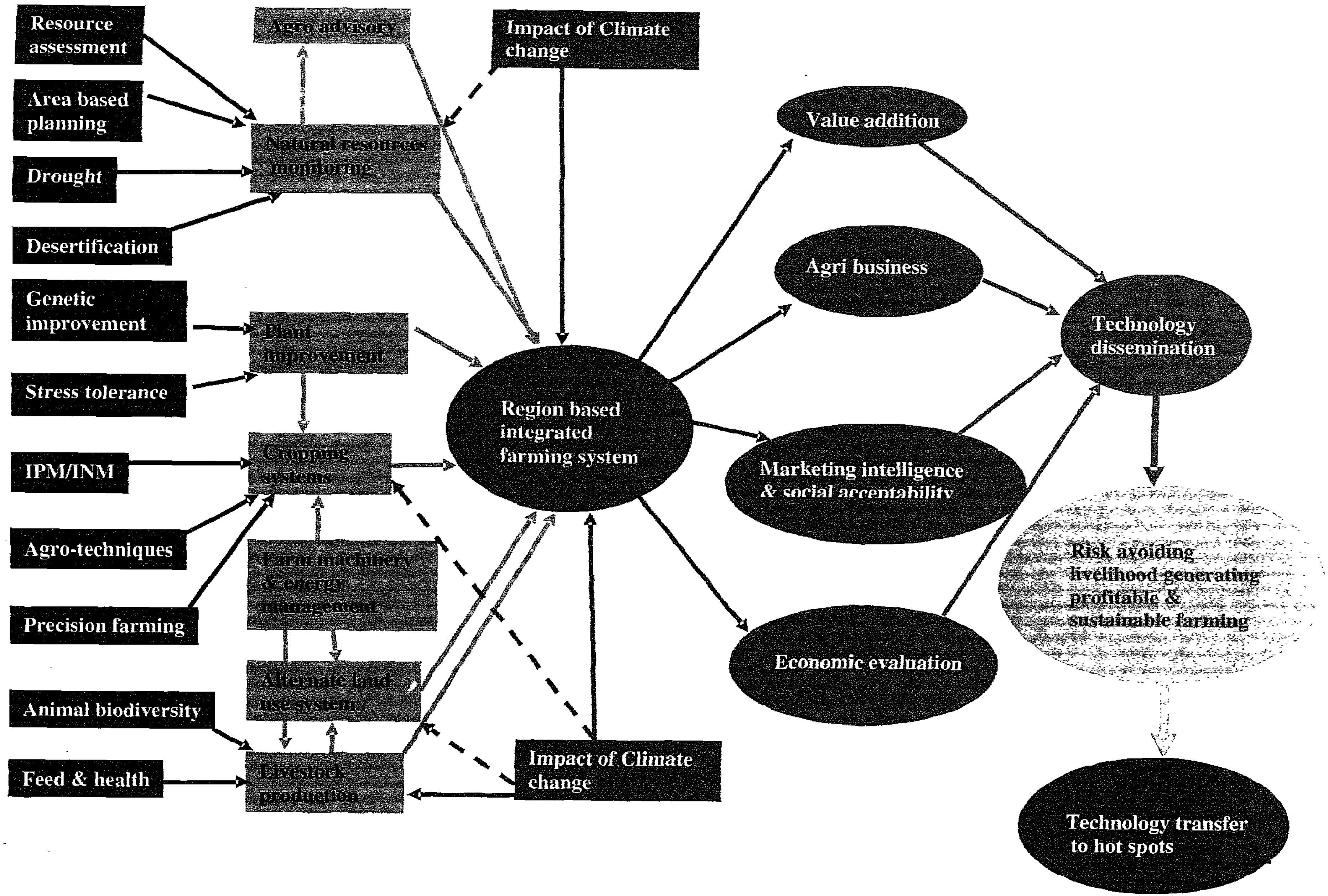

Fig. 21. Flow diagram showing linkages between different research activities.


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10. LINKAGES, COORDINATION AND EXECUTION ARRANGEMENTS

LINKAGES

As a premier research institute involved in basic, strategic and anticipatory research in arid regions, CAZRI is required to have better linkages at the regional, national and international levels so as to lead the research efforts to manage natural resources despite increasing pressure on them, meeting expectation of the people and cope up with the fast changing international scenario. Efforts are required to enhance the quality of research output on the one hand and early diffusion of proven technologies to the target groups on the other.

In the past, collaboration of CAZRI with CSIRO, Australia, UNESCO's Arid Land Programme, Indo-Canadian, Indo-Japanese, Indo-US programmes and UNCCD have been very fruitful. A number of training courses for research officers of Afro-Asian countries sponsored by International Institutions like UNESCO, UNEP, FAO, DANIDA, etc., have been successfully organized. A few more are in the offing. Nationally the linkages are being fostered with ICAR institutes, SAUs, state line departments, other central and state ministries, including the Ministry of Science and Technology, Department of Space and its research centres, Ministry of Environment and Forests and some of its institutes, IITs, non-agriculture universities, etc. Linkages are also being established/ strengthened with a number of CGIAR Institutes (ICRISAT, IWMI, ICARDA, IFPRI), CABI, UN Agencies (including UNCCD), US-PL 480, Agriculture Canada, Government of Israel, JIRCAS, etc.

Further linkages will be developed, both within the country and abroad. Within the country, stronger cooperation will be pursued with ICAR Institutes, SAUs, concerned state departments, NABARD, non-governmental organizations, and local bodies. More focus will be given to institutions that help in technology dissemination, as also on those that help build up knowledge and its translation to technologies. To address the climate change issues, new collaborations are envisaged with The Energy Research Institute, Indian Institute of Science, Indian Institute of Tropical Meteorology, India Meteorology Department, etc. In the international level, efforts would be made to get benefit of the knowledge and expertise in World Meteorology Organization and Inter-Governmental Panel on Climate Change, National Institute of Environmental Sciences, Japan, as well as other leading universities/institutions of the world, who are dealing with different sub-fields of climate change impacts, especially agriculture in the drylands.

Linkages are also envisaged with institutes in different arid land countries, especially in sub-Saharan Africa and Egypt where demands for CAZRI technologies have been perceived during several international training courses and other interactions. Linkage with institutes working on arid land problems in Australia, Israel, USA, China, Russian Federation, and several European countries engaged in arid land research, will also be explored for exchange of ideas and knowledge for mutual benefit.

TRAINING

A large number of technologies for sustainable development of arid ecosystem have become available through multidisciplinary research approaches at CAZRI. Quite a few of these have already been fine-tuned and tested on farmers' fields under different agro-climatic situations. For sustained impact, there is a need to have trained and devoted developmental personnel at various levels. It is, therefore, proposed to further strengthen the Institute's programme on technology transfer by establishment/strengthening of the following training and service units:

National Centre on Desert Technology

Trainers' Training Centre

Farmers' Training Centre

Farmers' Service Centre (ATIC).

National Centre on Desert Technology: This will provide six months' training courses to in-service personnel of State Governments and other organizations so as to prepare a Core Group of officers in different states for formulation and execution of various development plans. The Centre will also serve the needs of short-term training for international clientele.

Trainers' Training Centre: The Institute has been organizing training of development personnel as sponsored by various state governments and other organizations. A regular training mechanism needs also to be established for Trainers' Training at the Institute, which will impart further training to the Trainers of field workers.

Farmers' Training Centre: Ultimate benefit of all the capacity building rests on hands-on training of end-users for technology diffusion. These will be strengthened through KVKs and Extension wing of the Institute through regular programmes.

Farmers' Service Centre (ATIC): The Agricultural Technology Information Centre (ATIC) at CAZRI provides single-window service to farmers for solving their problems on agricultural and related issues. This centre will be strengthened to provide improved materials and products, and also as a forum to promote dialogue between farmers and scientists.

COORDINATION ARRANGEMENT

The Institute is organized into seven multi-disciplinary Divisions, and four Regional Research Stations. Heads of Divisions/Regional Research Stations coordinate the research progamme as decided and approved by the Research Advisory Council of the Institute, while the research projects are finalized after thorough discussion in Institute research council meetings. Inter-divisional and inter-institutional coordination is performed by Director, assisted by the Research Coordination and Management Unit. At the National level, programmes are coordinated by the Deputy Director General (Natural Resources Management), under the overall guidance of Director General, ICAR.

Coordination among research, training and development sectors is vital for technology transfer and adoption by the farmers, which need to be strengthened. A sound coordination system needs to be developed between the Institute, universities and state government agencies for faster dissemination of technologies to end-users.

EXECUTION ARRANGEMENT

Central Arid Zone Research Institute will continue to execute its research programme through a strong core group of scientists representing more than 30 disciplines. The focus of research is on farming system approach in a mission mode. Therefore, emphasis in the proposed plan has been given to on-farm research with people's participation. In this approach, development agencies and NGO's are likely to play pivotal role in promoting community participation, dissemination of technology and community maintenance of the assets and also in sharing responsibility of systems so developed.

11. CRITICAL INPUTS

The Institute has adequate infrastructure for research in frontier areas. A balance is maintained between basic and applied research. Modernization and updating of facilities is a continuous process in the era of global competitiveness. Several new programmes would be initiated and some of the on-going programmes would be strengthened to meet the objectives of our vision and the changing global scenario. Some advanced laboratories need to be set up, especially on biotechnology and molecular biology, while facilities for remote sensing-GIS and soil analysis will be upgraded. Possibility would also be explored to set-up pilot projects for exploitation of plant-based products for commercial exploitation. Generation of funds from other sources, both within the country (DBT, DST, ISRO, etc.), and abroad (FAO, World Bank, USDA, CSIRO, etc.) would also be explored. Resource mobilization and revenue generation would be given due emphasis so as to utilize the generated funds for furthering the research activities. Provision for Rs. 50 crore would be kept in Plan funds for development and reinforcing of the infrastructure, both at the headquarters (Jodhpur) and at Regional Research Stations at Bikaner, Pali, Jaisalmer and Bhuj.

It is also necessary to provide full benfits of IT revolution to the institute for collection, collation, interpretation and dissemination of knowledge/data. Scientific skill requires continuous upgradation and HRD is a priority, particularly in the disciplines where less manpower is available. Training of scientific manpower in frontier areas of research in International Institutions within India and abroad will be fruitful. Scientific exchange of ideas through participation of institute scientists in the international seminars, symposia, etc., needs to be encouraged. Inter-disciplinary research needs greater focus than hitherto. In future CAZRI will require additional scientific manpower and skill to achieve the goals envisaged in the plan. The research farm facilities also need to be further strengthened. Collaboration with national and international scientific research organization will help in multidimensional growth.

The Institute would be completing 50 years of its existence in October 2009. To mark the Golden Jubilee celebration, special efforts would be made to organize symposia, brainstorming sessions, farmer-scientist interactions, both at the Headquarters and Regional Research Stations. A number of other activities befitting occasion would also be organized. For these purposes provision of funds would be kept in the future Plan proposals.

12. RISK ANALYSIS

Sustainable development of our arid lands is challenging, especially due to its fragile environment, unpredictable and aberrant weather, poor resource endowment, large population base, both humans and animals which make a living from agriculture, and smaller investments due to non-commensurate returns. Yet, a rich traditional knowledge base and centuries-old practices to maintain the symbiotic relationship between the natural ecosystem and agriculture have many a times helped inhabitants to tide over the crisis and continue with the largely subsistence farming systems. Development initiatives during the post-independence era, and mostly during the last three decades, as well as gradual affluence due to the favourable impacts of new technologies on agriculture, however, put more demands on the natural system, and stretched it to the extent that many of the resources are showing signs of degradation/depletion, which in turn is impacting sustainability. Even though 23 per cent of western Rajasthan's population is below poverty line (as against 32% in the state), and ~25% of farmers have small and marginal holdings, the unsustainable practices may become a critical factor for enlarging the poverty base, or weaning away of the potential farmers to other sectors. As discussed in Chapter 6, uncertainties due to climate change will also impact the agriculture and increase the risk, and as highlighted in Chapter 7, we need to focus more attention on assessing the risks of desertification and drought, strengthen the farming systems by appropriately factoring the relative strengths of crop and livestock sectors that ensures improved land management and restores system functions, carry out structural changes in cropping systems through biotechnological and other scientific tools to allow crop diversification and a shift from the high-input, but unsustainable agriculture to a low-input but stable and sustainable agriculture. Water management, importance to economically important local plant materials, value addition to products for market, creation of value chains for crop and livestock products, efficient harnessing of non-conventional energy, strengthening of traditional knowledge, sharing of knowledge and developing linkages with stakeholders are the other issues that need better attention. Here we provide an analysis of the Strength, Weakness, Opportunities and Threats (SWOT) to assess the scope for ushering in the changes.

SWOT ANALYSIS

Arid ecosystem undisputedly inherits many weaknesses and threats, but has a few strengths and opportunities also. Our endeavour should be to convert threats into opportunities and weakness into strength for sustainable livelihood in this fragile ecosystem. An analysis of the zone's strength, weakness, opportunities and threats (SWOT) is provided in Table 13.

Strength lying in the hitherto unexploited resources may soon become a major threat to sustainability, if protective measures are not adopted. Gypsum deposits, a readily available resource, could be gainfully utilized to reclaim sodic soils. Livestock, providing livelihood to about two-third of the population in Rajasthan, is a mainstay for desert people. Hence, improved livestock husbandry involving breeding, feeding, health and management is a must for faster growth and better production from the livestock-based farming system. There is tremendous potential to deploy environment-friendly animal power for draft purposes as well. The treasure of livestock breeds of arid region forms an asset as they excel in productivity under stress conditions and possess disease and pest resistance as well. This wealth needs to be preserved and better utilized, especially in the light of the likely worsening of climate in the westernmost part when crop cultivation may face a real challenge.

Table 13. SWOT analysis for arid western Rajasthan

Issue	Strength	Weakness	Opportunity	Threat
Climate	Well defined monsoon cycle; dry environment; high solar radiation & wind velocity	Low & erratic rainfall; temperature extremes & stormy winds; high ET	Due to seasonality of monsoon cropping possible; conducive environment for quality seed production; harnessing solar and wind energy for agricultural uses	Frequent droughts, and desertification; wind erosion; instability in production systems
Land	Vast culturable land area; large areas of vegetated dunes with fine sand; wide interdunes and alluvial plains; plenty minerals; oil/gas	Large wastelands with poor vegetal cover; large area under poor capability	Excellent scope for harvesting run-off from rocky terrain; high potentials for biological production from wastelands; scope for mining, industries, tourism	Land fragmentation; over-exploitation of marginal lands leading to environmental degradation and reduced water recharge
Soil	Deep soils; well drained; friable mulching soils; early to attain FC and tilth; low run-off, rich in K	Low water holding capacity; high infiltration; weak structure; low in C & fertility; low microflora & fauna; low P availability; at places shallow hard pan	Well drained soils; good aeration; responsive to management; quick leaching of salts	Fragility; high oxidation; high wind erosion leads blockage of road, rail, canal; prone to salinization due to hard pan
Water	Limited availability of ground and canal water; abundance of traditional wisdom	Inadequate surface water; poor quality ground water; deep water table; limited scope of ground water recharge	Conjunctivae use of poor quality water; salt extraction; scope for fisheries in waterlogged & brackish water areas	Over-exploitation of ground water; excessive native salts; water logging & salinization; invasion of new pests and diseases, fluorosis, nitrate toxicity & ground water pollution
Vegetation	Rich and unique biodiversity; adapted multipurpose trees; shrubs and grasses; dual purpose, short duration and low water requiring crops	Poor vegetal cover; slow-growing trees; low yields; under-utilized plants; vegetation establishment difficult due to biotic & abiotic stresses	Medicinal, aromatic and energy plants; potential to improve degraded pastures & wastelands; scope for silviculture, horti-pasture and arid horticulture	Over-exploitation of limited vegetation, erosion of biodiversity, invasion of fast growing exotics
Agriculture	Strong self-sustaining farming system base, supported by traditional agro-forestry; at places canal	High rainfall dependant; short growing seasons; limited crop choice; low technological input	Scope for technological interventions, crop diversification, value addition, agro-industry, and organic farming;	Low profitability; declining ground water; vulnerable to diseases and pests including small

	irrigation available		strategic alliance at regional and global levels	mammals; threat to endemic plants; adoption of high water requiring crops
Animals	Rich animal biodiversity and wild-life; hardy livestock sustain on poor qualify feed & water; migratory habit; dairy network	High livestock and population growth; low productivity; unplanned breeding	High potential for livestock, poultry and fish production; potentials for strengthening dairy network, product processing/value addition; scope for employment generation.	Purity of native races; shrinking and degradation of pasture; Decline in wildlife and biodiversity
Humans	Strong social fabric; low expectations; excellent artisanship; pastoralism; outsourcing	Densely populated desert; high population growth; illiteracy; poverty; social evils like early marriage; gender biased; drug (opium) addiction; poor nutrition and health care; inadequate means of livelihood	Plenty of labour and human resource; amicable to discipline; immense scope for tourism and agro-industries	Migration to urban areas; higher population growth; encroachment on oran and gauchars and marginal lands for intensive cultivation
Organization	Well equipped multidisciplinary institutions; SAUs, state Deptts, research organizations and NGO; pluralism	Weak collaboration & linkages with stake holders; inadequate HRD, low potential for resource generation	Multi-location interdisciplinary programs; scope of linkages and synergy; sharing of resources and net working	Overlapping of R & D efforts, poor coordination

13. REVIEW

SYSTEM FOR REVIEWING CAZRI'S ACTIVITIES

The activities of CAZRI are guided and reviewed every five years by a Quinquennial Review Team, and every year by a Research Advisory Committee, as well as an Institute Management Committee. Besides, the Staff Research Council (now Institute Research Council), which consists of all the scientists of the Institute, meets every year to discuss and finalise the yearly research activities. There is also Institute Joint Staff Council, which meets more than once in a year to discuss staff welfare.

STRENGTH OF CAZRI'S RESEARCH

As a result of continuous research efforts by CAZRI, several alternatives are now available to farmers. Crop diversification is vital for insurance against risk and for this purpose reluctance on the part of farmers to accept the change will have to be overcome by education and participatory demonstration. A range of indigenous and exotic plant materials available for cultivation, either as supplement to existing crops or as replacements, constitutes a source of strength. Adoption of integrated farming systems (animals + grasses + arable crops + trees/shrubs/horticultural crops) may mark the beginning of a positive shift in the lives of the people in the region.

An account of the technologies developed by CAZRI and their impact have been provided in Chapters 4 and 5. Based on the knowledge base and the technologies, Institute provides advisories and consultations to different agencies and individuals both within and outside the country. Some of the technologies have been owned by state government agencies and have become parts of their package of practices for development work, while some are regularly used by other stakeholders. This includes sand dune stabilization, shelterbelt plantation, water conservation structures, watershed management, sodic soil amendment procedure, crop, fruit and grass varieties, cropping systems and agronomic practices, enhancing gum production from trees, livestock management procedure, animal feed making, etc. Several other technologies are also in the pipeline, including value addition to plant and animal products, research on which are giving encouraging results (discussed in Chapter 4).

The strength of the Institute in horticultural research has so far been translated into output and outcome in the form of a complete package of Ber cultivation that now provides livelihood and nutritional security to millions across the nation. It is time to further build upon this strength to provide nutritional security and livelihood to the developing nations in Sub-Saharan Africa and other potential countries.

The success of arid watershed management, including soil and water conservation practices, has now provided the Institute strength to share this technology with the developing Third World countries across the globe having similar arid conditions, especially in Asia, Africa and Latin America.

Similarly, the strength of the Institute in integrated pest management, especially those based on Neem and soil bacterial cultures for managing soil-borne pathogens, can be shared with other arid land countries that are similarly handicapped by pest problems.

Hand tools and seed drills being developed especially by the Institute for arid conditions can be tested and used in the neighbouring states with similar terrain conditions.

A good number of value added products from locally available plants and animals are in the offing, including those from *Citrullus colocynthes* (Tumba), *Salvadora oleoides* (Peelu), *Aloe vera*, goat kulfi and goat paneer, etc., which will not only have good market potentials, but will also help the rural households with additional livelihood options.

CAPACITY BUILDING OF THE INSTITUTE

In summary, CAZRI's research suggests that the per capita income of farmers of the region can be boosted by adopting integrated farming system approaches, efficient utilization of water, crop diversification and product processing linked to value chains, provided the technological modules developed and upgraded from time to time receive wide adoption. This calls for strengthening of the extension activities and of the links with state line departments, as well as participation of farmers from planning through marketing stage. Value chains are to be established from the farming to the marketing stage, and cooperative movements have to link the farm produces to markets to harness maximum benefit.

Interdisciplinary teams of scientists are engaged in CAZRI to find solutions to the multidimensional complex problems faced by the farming communities of arid region, especially to enhance productivity of the systems while protecting the environment on sustainable basis. However, the existing scientific staff and research facilities in the institute, including those in its regional research stations, need vast upgradation, while new facilities are to be created to appropriately monitor and analyse the subtle changes in land system dynamics through advanced remote sensing and GIS applications, other sophisticated equipments for soil parameters, as well as to monitor, network and analyse the weather variables to provide real-time agro-advisory across the region, and for characterization of genomic codes of the available biological resources, carbon dynamics, etc. Simultaneously, human resource development of the scientific and technical manpower in expanding their knowledge and skill to the currently available knowledge at the global level is also necessity.

14. RESOURCE GENERATION

Most of the programmes identified in the document are long term in nature, which will require dedicated efforts at various levels. Besides Institutional support, generation of resources would be needed through externally funded projects and consultancies at national, as well as international levels. It is to be appreciated that resource generation in arid ecosystem is difficult due to frequent droughts, mono-cropping and low-value crops. However, efforts are required to explore the possibilities of raising crops that have industrial and medicinal values and complement resources through internal resource generation by increasing efficiency of resource use through technologies developed by the institute, trainings, consultancies, contract research, patents and involving corporate sector.

Resource generation through consultancies, sale of value added products, and improved planting materials is on the rise during last couple of years (Table 14). Training programmes, both national and international, will be organized on subjects for which expertise is available in the Institute. Seeds of improved crop verities developed by the Institute are in great demand among farmers of the region. Similarly seeds of forage range grasses are available in the Institute. The grass seeds will be popularized and sold to farmers and other stakeholders. There is great demand for processed fruit products also. Processes standardized for value addition to these fruit products would be patented. Likewise, local plants and animals would be screened for exploitation of industrial products. These include plant products having potential for pharmaceutical and IPM application. Contract research and providing contract services would also help in resource generation. Guar gum has high commercial value and demand of gum is increasing. Therefore, efforts will be made to generate resources through interaction with industries and improving both productivity and quality of guar gum. Efforts will be intensified to increase the pace of resource generation.

Table 14: Institute budget and resource generated during IX and X Plan period

Year	Budget		Resource generation
	Plan	Non-plan	
IX Plan			
1997-1998	120.00	800.0	26.17
1998-1999	170.00	1086.0	26.20
1999-2000	175.00	1084.0	24.49
2000-2001	125.00	1153.75	37.13
2001-2002	205.00	1263.00	44.70
X Plan			
2002-2003	88.00	1249.00	41.26
2003-2004	190.00	1284.00	48.06
2004-2005	248.00	1402.00	41.41
2006-2007	217.00	1622.00	72.56
2007-2008	200.00	1508.00	75.00*

*Targeted.

15. OUTPUTS

CAZRI dreams of sustainable arid land management through farming systems approach to provide better livelihood to the desert inhabitants, and at the same time to maintain economically exploitable green cover that improves the desert environment. This involves research on conservation agriculture, maintaining a balance between resource use and environment health. For achieving these goals a number of research outputs are proposed to be delivered, which include quantitative and time series information on appraisal and monitoring of natural resources and desertification through GIS in digital format for different agro-climatic zones in a phased manner, suggested land uses at district level to maintain sustainability, a complementary database on biodiversity, technology packages for integrated farming involving annuals, perennials, livestock, some new crop and grass varieties that can address the changing climatic and demand scenarios of the region, technology for making cheap and nutritious feed concentrates from locally available resources for the region's livestock, several value-added plant and animal products, and few small and affordable farm tools and renewable energy-harnessing devices. These products will be need-based, cost-effective and location-specific as greater emphasis is given to on-farm research with people's participation.

It is expected to acquire 20 and more patents for value-added plant and animal products, innovative processes, hand tools and other agricultural equipments. Research results will continue to be published in national and international journals, as well as in books/bulletins for information of the scientific communities, and in popular journals (including those in local language) for farmers, other stakeholders and general public. An average of 180-200 publications per year is contemplated from the Institute.

16. OUTCOME

Assuming that climate will not turn worse than what it is now, and also assuming that the human and livestock populations will continue to rise, the large-scale adoption of the technological capsules being developed and refined would result in increased productivity and overall production of crops. It is estimated that the technology adoption will not only bridge the narrow gap between the region's demand and supply, but will also create 2-3 fold surplus in the availability of cereals and pulses. Eventually this may release reasonable area of land for pasture development through technological mediation, which will not only meet the fodder scarcity, particularly during drought years, but when effected with the concurrent livestock management programme, will also create more than two-fold surplus in milk and meat production over the region's demand. Gaps between the region's demand for horticultural products and their supply would perhaps still remain, and would require several other interventions than technological (e.g., policy interventions, agro-processing facilities, transport and marketing facilities, risk coverage, etc.). Yet, overall the spread of the technologies will bring sustainability to rainfed agriculture, in addition to providing better nutritional security and sustainable livelihood, and increasing its share in the state's NSDP (net state domestic product) as well as in country's overall GDP.

If, however, the climate changes for worse, and faster than assumed, there is less likelihood of the present set of technologies doing wonders everywhere. Rise in CO_2 level may not allow the C_4 plants to function better, while rise in temperature may play havoc with agriculture in totality. As mentioned in Chapter 6, a 2.0°C rise in temperature with 7% increase in rainfall may lead to 7% fall in agricultural GDP, while a 3.5°C rise in temperature with 15% rise in rainfall may lead to 25% shortfall in country's agricultural GDP. Shifts in rainfall regime may also upset the crop calendars. Stress tolerance capacity in the plant varieties being developed by the Institute, may help to alleviate the problem to certain limits, and maintain the production level, while anticipatory research on other biotechnological interventions, or to address the crop phonological changes, may help in halting a reversal trend in production.

If the rainfall does not increase with temperature (as is expected in north-western part of the region) the conditions will be very challenging for agriculture. To address such problems we need to have much better understanding of the nature, direction and magnitude of the changes, and develop new technologies that can adequately meet the stresses. New anticipatory research programmes have been suggested to address the issues, and hopefully these will lead to technology development for stabilizing the production, if not increase the output under a worsening climate. Livestock-based farming systems may withstand the shocks better, and hence our emphasis on strengthening it through appropriate research and policy interventions, especially in the drier parts.

CAZRI is committed to provide measurable output to meet the increasing challenges in agriculture of the arid region as well as that of the country, and is constantly upgrading its knowledge base and technologies.

ANNEXURE – I

Botanical name of some important plants in western Rajasthan

Name of plants	Botanical name
Peal millet	*Pennisetum glaucum*
Moth bean	*Vigna aconitifolia*
Mung bean	*Vigna radiata*
Clusterbean	*Cyamopsis tetragonoloba*
Horse gram	*Dolichos uniflorus* Lam.
Sesame	*Sesamum indicum*
Castor	*Ricinus communis*
Cowpea	*Vigna unguiculata*
Mustard	*Brassica campestris* L. var. sarson
Taramira	*Eruca vesicaria*
Rape	*Brassica campestris* L. var. toria
Groundnut	*Arachis hypogea*
Cumin	*Cuminum cyminum*
Isabgol	*Plantago ovata*
Pomegranate	*Punica granatum*
Aonla	*Emblica officinalis*
Bael	*Aegle marmelos*
Kair	*Capprais deciduas*
Matira	*Citrullus lanatus*
Tumba	*Citrullus colocynthis*
Sena	*Cassia angustifolia*
Guggal	*Commiphora wightii*
Kummat	*Acacia senegal*
Rohira	*Tecomella undulata*
Khejri	*Prosopis cineraria*
Neem	*Azadirachta indica*