Major Achievements of Decade (2011-2020) at ICAR-CAZRI RRS, Bhuj

ICAR-Central Arid Zone Research Institute
(ISO 9001:2015)
Jodhpur 342 003 (India)

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Director
ICAR-Central Arid Zone Research Institute
Jodhpur - 342 003 (Rajasthan) India
Phone : + 91 291 2786584, + 91 291 2788706
E-mail:director.cazri@icar.gov.in
Website: www.cazri.res.in

Contributors:

Anandkumar Naorem

Abhishek Patel

D. Machiwal

भारतीय कृषि अनुसंधान परिषद
कक्ष क्र. 101, कृषि अनुसंधान भवन–II, नई दिल्ली–110 012, भारत
INDIAN COUNCIL OF AGRICULTURAL RESEARCH
Room No. 101, Krishi Anusandhan Bhavan-II, Pusa, New Delhi 110012, India

डॉ सुरेश कुमार चौधरी
उप महानिदेशक (प्राकृतिक संसाधन प्रबंधन)
Dr. Suresh Kumar Chaudhari
Deputy Director General (Natural Resource Management)

Foreword

The vast arid landscape of Gujarat, encompassing 6.22 million hectares and accounting for 19.6% of India's arid zone, presents both a profound challenges and unique opportunities. Kutch, the second largest district in India, epitomizes this dichotomy with its diverse ecological spectrum ranging from seasonal wetlands and thorn forests to expansive deserts and mangrove coasts. Within this rugged and variable environment, where water is a precious and unpredictable resource, the quest for sustainable agricultural practices becomes paramount. Since its establishment on March 26, 1987, the Regional Research Station (RRS) of ICAR-CAZRI at Kukma, Bhuj, has been at the forefront of addressing the complex needs of this arid region. The station has dedicated itself to enhancing agricultural productivity and sustainability through a suite of innovative strategies and has made invaluable contributions, by developing fodder-based farming systems suited to arid conditions, designing region-specific land-use systems, and identifying improved forage varieties to creating sustainable agri-horti models and enhancing key crop cultivars.

It's impressive to see how the RRS Bhuj has become a valuable asset for the state government, State Agricultural Universities, and other governmental departments over the years of its existence and the able leadership and guidance of past and present directors.

It is with a pleasure that “Major Achievements of Decade (2011-2020) of RRS Bhuj” is being published. This publication stands as a testament to the dedicated efforts of the RRS Bhuj staff and their unwavering focus on the challenges and opportunities within the arid ecosystem. The compilation offers a treasure trove of knowledge and practical insights into issues such as salinity management, fodder production, and the cultivation of grasses in arid regions, all grounded in the research conducted at ICAR-CAZRI RRS Bhuj.

(S.K. Chaudhari)
Deputy Director General

Ph.: +91-11-25848364 Fax: +91-11-25848366 Email: ddg.nrm@icar.gov.in Website: www.icar.org.in

भाकृअनुप
ICAR

INDIAN COUNCIL OF AGRICULTURAL RESEARCH
NRM Division, Krishi Anusandhan Bhavan-II
IARI Campus, Pusa, New Delhi 110012, India
Tele.: 011-25846457
Email: adgagroandaf@gmail.com

Rajbir Singh
ADG (AAF&CC)

Message

This decadal achievement of CAZRI RRS Bhuj is a testament to the dedication of the institute towards addressing the unique and challenging conditions of the arid regions, particularly in the Kachchh district of Gujarat.

The arid landscapes of this region are characterized by extreme temperatures, erratic rainfall, saline soils, and limited water resources. In response, ICAR-CAZRI, RRS Bhuj has developed and implemented innovative agro-technological solutions aimed at increasing agricultural productivity and ensuring sustainability in this fragile ecosystem.

This station's pioneering work on soil conservation techniques, and the management of saline and marginal quality water resources has greatly enhanced the viability of agriculture and enhanced the livelihood of local farmers by increasing the productivity, even under the harshest conditions, by ensuring optimal water use and soil health.

It is pleasure to know that for the crop diversification, CAZRI Regional Research Station, has done quality work on cactus pear as a sustainable fodder resource for arid climates that offering a resilient alternative to the livestock owners of this arid region in the face of increasing droughts and water scarcity. The station's commitment to addressing the evolving challenges of climate change, water scarcity, and soil degradation ensures that it will remain a pivotal force in improving the livelihoods of farmers and the ecological health of Kachchh.

I extend my sincere appreciation to the dedicated scientists and staff, whose tireless efforts have made these achievements possible. I am confident that the knowledge generated during this decade will serve as a foundation for continued success in the years to come.

(Rajbir Singh)
Assistant Director General (AAF & CC)

भाकृअनुप–केन्द्रीय शुष्क क्षेत्र अनुसंधान संस्थान
(भारतीय कृषि अनुसंधान परिषद्)
जोधपुर - 342 003 (राजस्थान), भारत

ICAR-Central Arid Zone Research Institute
(Indian Council of Agricultural Research)
Jodhpur - 342 003 (Rajasthan), India

डॉ. ओम प्रकाश यादव
निदेशक
Dr. O.P. Yadav
Director

Message

Extreme weather characteristics like high temperatures, infrequent and irregular rainfall, saline soil, and scarce water supplies define the dry region of Kachchh. The Station has developed location-specific technologies to improve agricultural sustainability and production. Work on land and water management, field crops management, fodder resource management, and climate adaptation has been transformative in ensuring that agriculture remains a viable enterprise in these harsh conditions.

This station has also been at the forefront of promoting cactus pear (*Opuntia ficus-indica*) as a drought-tolerant fodder resource, which is been highly useful for livestock in the region. In addition, the station has made strides in the socio-economics evaluation of the pastoral communities in the Banni grasslands, assessing their livelihood and the crucial role of livestock, particularly Banni buffaloes, in the regional economy.

The Station success has been further bolstered by collaborative efforts with international and national partners that has fostered a spirit of knowledge exchange and innovation helping the station to work out solutions to the specific needs of arid regions.

Presenting the highlights of ten years (2011-2020) of research accomplishments of the ICAR-Central Arid Zone Research Institute (CAZRI) Regional Research Station (RRS), Bhuj is a great pleasure.

I congratulate all the scientific, technical, and administrative team of the station who are dedicated and committed to work for Kutchchh region. This compilation is not merely a reflection of past achievements made by the RRS Bhuj but a beacon guiding future endeavors in sustainable agricultural practices for the arid region of Gujarat.

(O.P. Yadav)
Director

Contents

Historical Background

The Indian arid zone occupies around 12% of the country's total geographical area. Most of the hot arid zone is predominantly found in Rajasthan (61%), Gujarat (20%), Andhra Pradesh & Karnataka (10%), and Punjab & Haryana (9%). The cold arid zone covers about 7 M ha area in some parts of Jammu & Kashmir, Ladakh and Himachal Pradesh. The hot arid region is generally characterized by limited precipitation (100-400 mm), high temperature and relatively low vegetation. General constraints for the arid areas are low and erratic rainfall, high temperatures, soil erosion, salinity in soil and water resources, limited availability of groundwater, seawater intrusion into aquifers in coastal arid lands, scarcity of fodder resources for livestock and other threats for agriculture and natural resources. On the top of it, climate change and variability pose a serious threat to crop production in arid region. Moreover, agriculture is a location-specific activity that requires adoption of scientific practices to get better yield and sustainability. Keeping these constraints in mind, the Central Arid Zone Research Institute, Jodhpur was established under the aegis of Indian Council of Agricultural Research (ICAR), New Delhi. ICAR-CAZRI is the sole institute in India conducting an extensive research on arid lands covering all areas of agriculture. Apart from having headquarter at Jodhpur, ICAR-CAZRI has five regional stations at Pali, Bikaner, Jaisalmer, Bhuj, and Leh.

In Gujarat, eight districts have their lands, either entirely or partly, under arid climate namely Kachchh (100%), Jamnagar (80%), Surendranagar (29%), Junagadh (20%), Banaskantha (18%), Mehsana (7%), Ahmedabad (6%) and Rajkot (6%). Looking at the acreage of arid region in agricultural production of Gujarat and existing problems of arid agriculture in this region, a Regional Research Station (RRS) of ICAR-CAZRI was established on March 26, 1987 at Kukma village of Bhuj taluka in Kachchh district of Gujarat. The purpose of establishing the RRS in Bhuj was proper assessment of the agriculture-related problems and identification and development of situation specific agro-technologies for the sustainable development of agriculture and allied sectors in the arid region of Gujarat. The arid region of Gujarat suffers from extreme conditions due to harsh climate, and hence, research at Regional Station of ICAR-CAZRI, Bhuj has been focused on identification of location-specific problems and constraints related to agricultural production and providing feasible solutions by developing suitable technologies. The efforts of the RRS, Bhuj are visibile in improving productivity of arid lands in the area, which have made it possible to adopt agriculture as a profitable enterprise in the arid Gujarat. Since its establishment, many research activities were undertaken at the station, which have resulted in development of various sustainable and economically viable technologies for arid agriculture such as identification of improved genotypes of grasses, characterization of resource base, identification of suitable forage legumes, development of silvipastoral, and agri-horti models and identification of improved cultivars of important field crops along with efficient intercropping systems, evolving quality grass-legume mixture and other alternate fodder resources, and rainwater harvesting for cost-effective irrigation. The station is also in the forefront in disseminating the agriculture knowledge base and giving advice/training to farmers through its outreach programs aiming at demonstration of tested technologies under the farming situation. Several training programs have been conducted at the station for the benefit of stakeholders.

The major disciplines in which research is being conducted at the station are agronomy, genetics and plant breeding, soil science, soil and water conservation engineering, environmental science, economic botany and agroforestry.

Thrust Areas

- Development of area-specific farming systems
- Managing saline soil and poor quality water for higher productivity
- Seed production of grasses and trees

Location

The RRS, Bhuj of ICAR-CAZRI is located at a distance of 2 km from Kukma village and 13 km from Bhuj, on Bhuj-Gandhidham highway in Gujarat State (Fig. 1). The area experiences a hot arid climate and receives an average annual rainfall of about 389 mm. A considerable portion (ranging from 38 to 68%) of the annual rainfall occurs with in consecutive 2 to 4 days in the area. On an average, the rainfall occurs in 13 rainy days with high potential evapotranspiration (1900 mm year^{-1}).

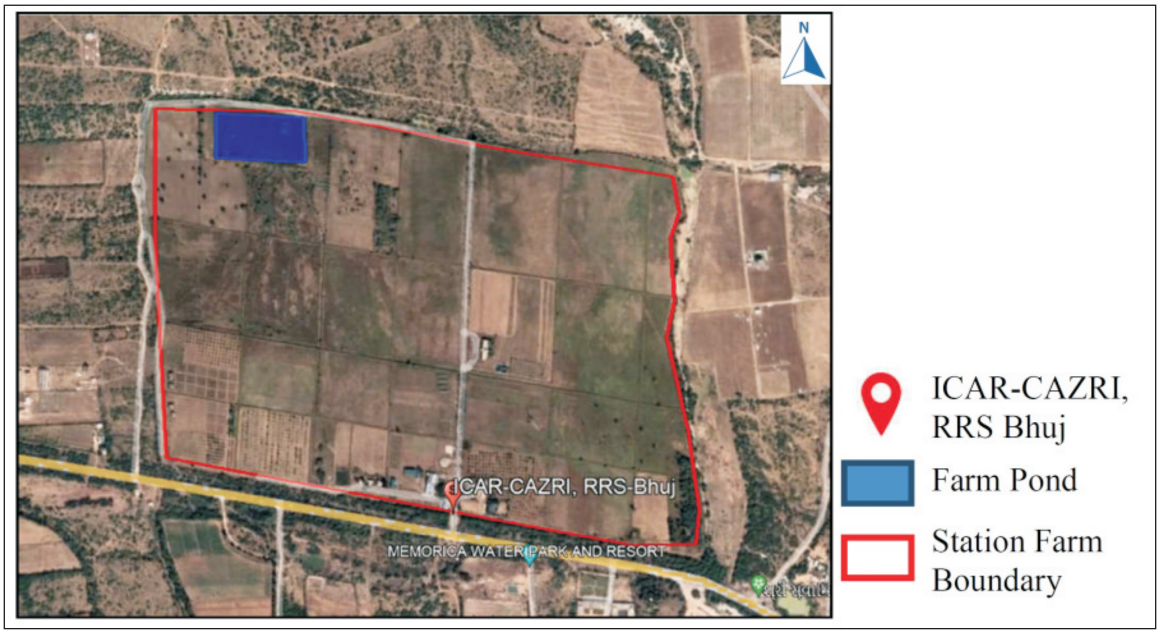

Fig. 1. Google Earth image of RRS of ICAR-CAZRI at Kukma, Bhuj, Gujarat

Facilities

Research Farm

The station encompasses about 58 ha area under research farm, which is situated near Kukma village. The entire farm area is divided into separate experimental blocks of about 2.5 ha size each. Landuse map of the farm area is depicted in Fig. 2. There is one small water reservoir of size 180 m × 90 m with less than 3 m depth at northwest corner of farm area having soil bunds at boundaries to restrict escape of runoff water from the farm boundaries. The reservoir stores surface runoff generated during excess rainfall in the farm area. Krishi Vigyan Kendra-Bhuj of ICAR-CAZRI, dedicated to deliver extension services to farmers of arid region in Gujarat, is also located in the premises of RRS, Bhuj. A water storage tank has also been constructed at the station to ensure water supply.

Library

The station has a library having more than 500 books on different agricultural disciplines. The library contains many technical bulletins and flyers of research activities accomplished at the station, which are available for farmers and visitors. In addition, the library has access to reputed national journals related to various disciplines of agriculture.

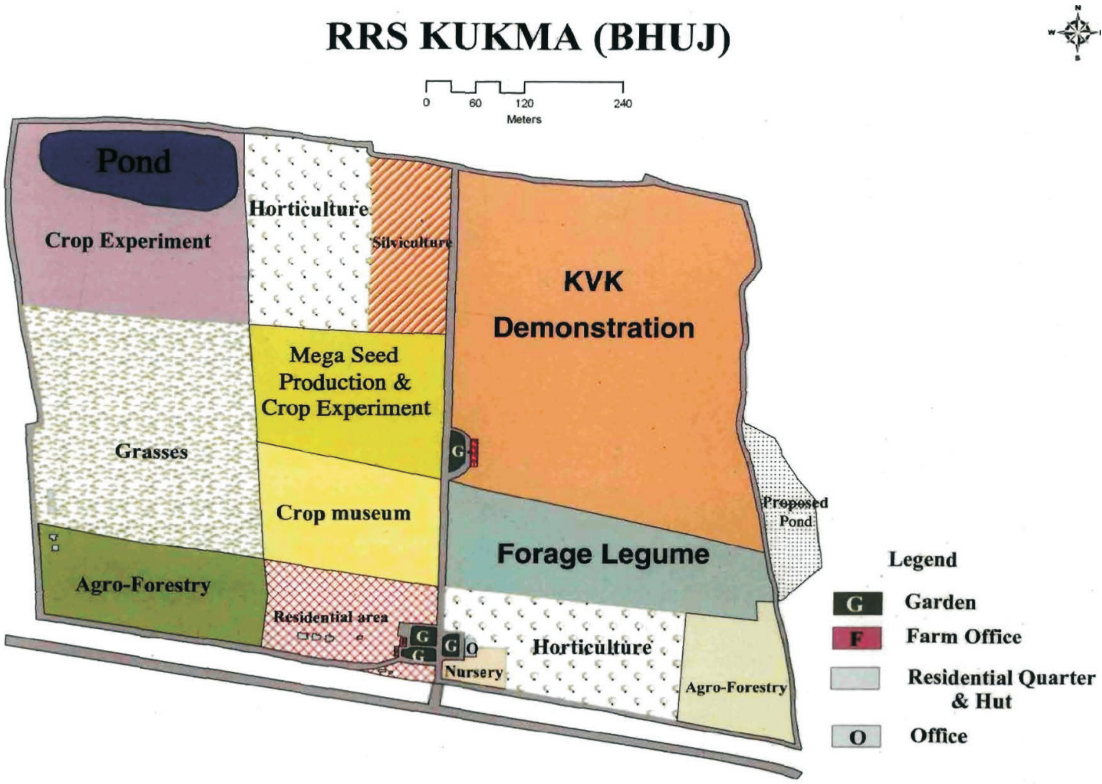

Fig. 2. Landuse map of Research Farm at Regional Research Station, Kukma, Bhuj

Laboratory

The station is having a well-maintained and equipped laboratory with more than 25 instruments for the analysis of soil, water and plant samples. Besides, institutional research activities the laboratory also provides facilities of soil and water testing to farmers of this region.

Meeting Hall

The research station has one meeting hall equipped with state-of-the-art audio-visual facility with a seating capacity of 20 persons for conducting meetings and farmers' trainings.

Research Achievements

Land and Water Resource Management

Development of a water balance model for evaluating feasibility of small reservoir

A water balance model was developed for accounting inflow and outflow of a reservoir constructed in research farm of the station. Reservoir water levels were monitored daily, and water balance components, i.e., rainwater directly falling into reservoir, surface runoff, irrigation extractions, and evaporation and percolation, were measured/ estimated (Fig. 3). Results indicated that rainfall has a fair control on harvested runoff. In year 2012, with 79 mm rainfall, the storage was only 925 m^3 of water with 66 cm depth. In contrast, reservoir was full of water (2.85 m depth) in year 2013 with storage of 24879 m^3 when rainfall totalled 291 mm. Percolation rate (0.14 cm hr^{-1}) from 24-hour infiltration tests revealed that reservoir storage may get depleted within 85 days. In 2013, a major portion (51%) of storage was lost through evaporation and percolation, and only 21% stored water could be utilized for supplemental irrigation (Fig. 4). Suitable measures need to be adopted to check evaporation and seepage losses of the reservoir.

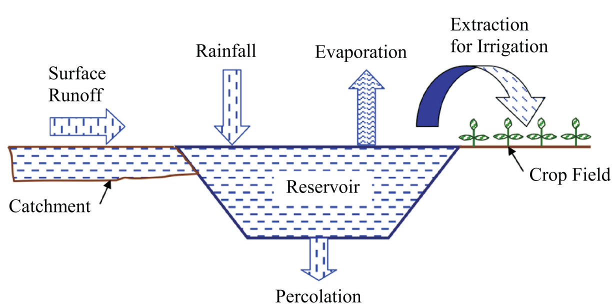

Fig. 3. Schematic diagram of reservoir water balance model

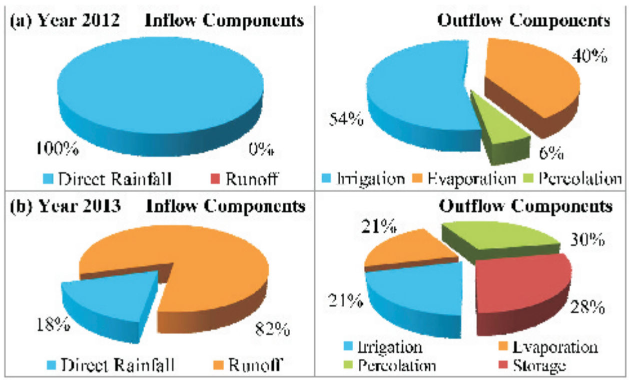

Fig. 4. Proportions of inflow/outflow components in (a) 2012 and (b) 2013

Cost-effectiveness of fainwater harvesting for irrigation

Cost-effectiveness of reservoir, constructed at the station (Fig. 5a,b) for providing irrigation to wheat and mustard crops, was evaluated. Cost of reservoir construction for storage capacity of 29,184.5 m^3 was estimated at Rs. 10,33,349. Cost of cultivation for wheat and mustard was worked out to be Rs. 41,800 and 31,100 per ha with net benefit of Rs. 28,901 and Rs. 38,835 respectively, which clearly indicated that mustard is 34% economical by better over wheat. The optimistic, pessimistic and average unit costs of stored rainwater over 30 year period was calculated as Rs. 1.51, 3.03 and 2.27 m^{-3}, respectively, which suggests that small reservoir is a viable option for rainwater management in arid regions. This finding is further supported from optimum values of benefit-cost (B-C) ratio (1.01), net present value (NPV~Rs. 10,093) and internal rate of return (IRR~10.12%). Demand-based efficient irrigation supplies further improved values of B-C ratio (2.18), NPV (Rs. 1,330,558) and IRR (24%).

Fig. 5. (a) Reservoir full of water and (b) view of mustard crop (Year 2013)

Quantification of soil erosion at catchment scale

Annual soil loss was quantified in Kukma catchment using the Universal Soil Loss Equation (USLE) model in conjunction with geographic information system. In absence of rainfall intensity records, monthly rainfall data were used to calculate rainfall erosivity factor (R). For computing soil erodibility factor (K), the empirical method required several parameters for each soil type, which were not available for catchment soils. Hence, information about texture, depth, and permeability were used to obtain K-values from literature, which were then adjusted based on local experiences (Fig. 6). Slope length (L) and slope steepness (S) factors were calculated separately by using digital elevation model (DEM) of 90 m pixel resolution downloaded from Shuttle Radar Topographic Mission (SRTM). The S factor was derived for slope length longer than 4 m. Google Earth image was used to classify the land use/land cover (LULC) into suitable classes for assigning the cover factor (C) and management practice factor (P). Results of the USLE model

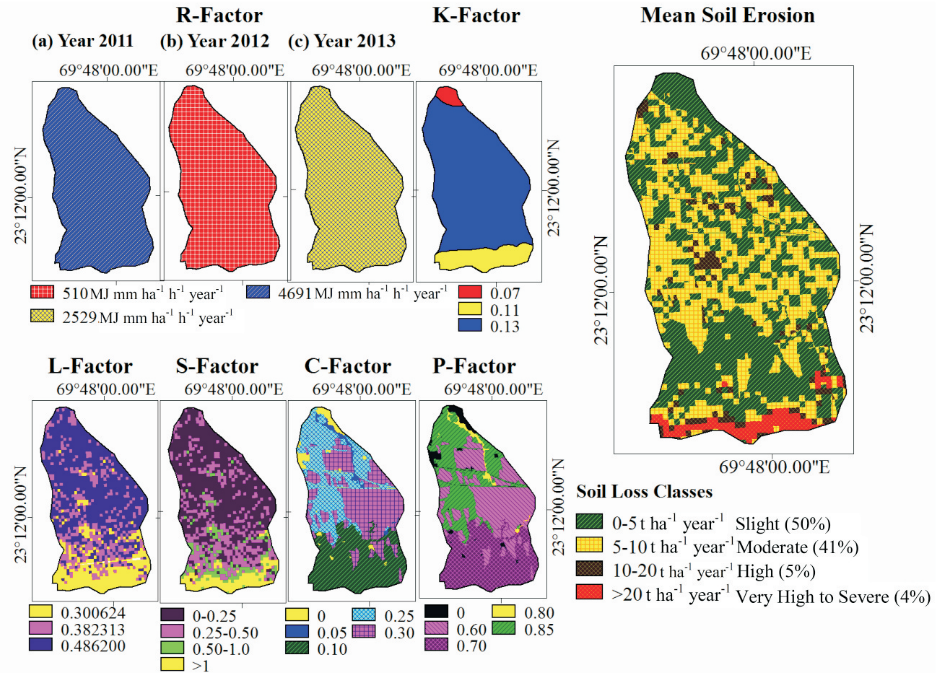

Fig. 6. Spatial by distributed maps of USLE factors and soil loss determined by using USLE model

revealed that the soil loss in the watershed ranged from <5 to slightly >20 tonnes ha^{-1} $year^{-1}$. The soil erosion potential in the area was slight (0-5 t ha^{-1} $year^{-1}$), moderate (5-10 t ha^{-1} $year^{-1}$), high (10-20 t ha^{-1} $year^{-1}$), and very high to severe (>20 t ha^{-1} $year^{-1}$) under 50, 41, 5 and 4% area, respectively (Fig. 6). Slight to moderate soil erosion was reported in a major portion of the area, while very high to severe erosion occurred in the southern portion where hillocks are situated.

Quantification of soil erosion at field scale

Runoff, soil and nutrient losses were estimated from four sole-crops, i.e., sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), mung bean (*Vigna radiata*), and clusterbean (*Cyamopsis tetragonoloba*) and four cereal-legume intercropping (Fig. 7a) with two controls, i.e., cultivated and unploughed fallows (Fig. 7b). Multi-slot divisors were fabricated and installed at all field plots of 20 m × 5 m size. Soil loss from field plots was monitored whenever runoff-producing rainfall occurred. The highest soil loss was recorded from cultivated fallow (108.03±49.95 kg ha^{-1} yr^{-1}) followed by unploughed fallow (78.95±28.42 kg ha^{-1} yr^{-1}). Mung bean is found effective in controlling soil loss both under sole crop (soil loss ~ 0.54-33.94 kg ha^{-1}) as well as intercropped with sorghum (soil loss ~ 0.60-23.37 kg ha^{-1}) and pearl millet (soil loss ~ 2.45-31.11 kg ha^{-1}). Analysis of variance revealed that runoff, soil losses and available soil nutrients are affected ($p<0.05$) by the runoff-generating rainfall, crop cover, and their sole- and intercropping practices. Soil erosion-crop productivity models were developed by multiple linear regression. Adequacy of the developed models was evaluated as good (R^2 ~ 0.75-0.90; modified Nash-Sutcliffe Efficiency ~ 1).

Fig. 7. Field views of (a) sorghum-clusterbean intercropping and (b) unploughed fallow plot with multi-slot divisor and runoff collection tank (Year 2013)

Development of erosion-productivity models

Soil erosion along with three soil chemical parameters, i.e., soil organic carbon (SOC), available P_2O_5 and available/exchangeable K_2O, were monitored from field plots (20 m × 5 m size) of four sole crops, i.e., sorghum, pearl millet, mung bean and clusterbean and four cereal-legume intercropping combinations. Crop yield was monitored at maturity of the plants. Unit circle plots of two significant factors identified through principal component analysis of 5 parameters (soil erosion, crop yield and three soil chemical parameters, i.e., P_2O_5, K_2O, and SOC), explaining 54.89-74.90% of total variance, were plotted (Fig. 8). On unit circle plots, crop yield is always opposed by soil loss and favoured by soil P_2O_5, K_2O, and SOC. Hence, crop yield has positive influence of chemical parameters and negative influence of soil erosion. All these parameters were used to develop soil erosion-crop productivity models by multiple linear regressions. Results indicated moderate to fair accuracy of the developed models with value of $R^2>0.90$ in 6 cases and $0.90\geq R^2>0.75$ in

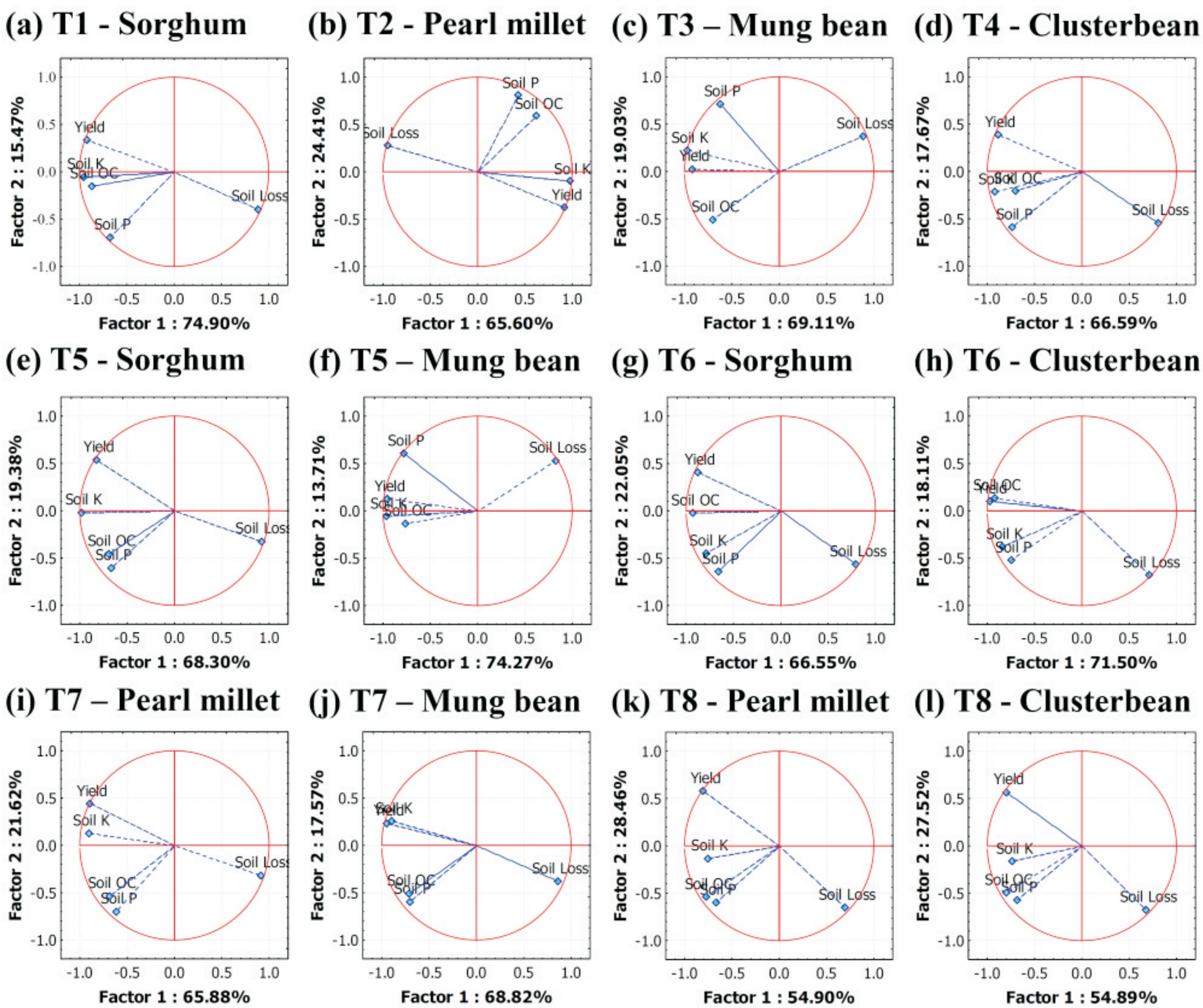

Fig. 8. Unit circle plots for first two significant principal components

6 cases. Similarly, adequacy of the developed models is found to be good from value of modified Nash-Sutcliffe efficiency approaching 1. Therefore, the developed models can be used successfully to predict change in crop productivity in response to varying soil erosion conditions.

Assessment of reservoir sedimentation from an arid catchment

Sedimentation in a reservoir, constructed at research farm of the station located in an arid catchment, was assessed by performing topographical survey. The survey database was subjected to SURFER software to generate grid, contour map and three-dimensional digital model of the reservoir by interpolating reduced levels using kriging (Fig. 9). Storage volumes were computed at 1 cm interval using trapezoidal formula and depth-capacity curve was developed. It was estimated that maximum depth of 2.85 m corresponds to full storage capacity of 24879 m^3. The capacity of the reservoir got reduced by 4305.5 m^3 (14.75%) over a period of 12 years (2001-2012) due to sedimentation occurred at an average annual rate of 358.8 m^3.

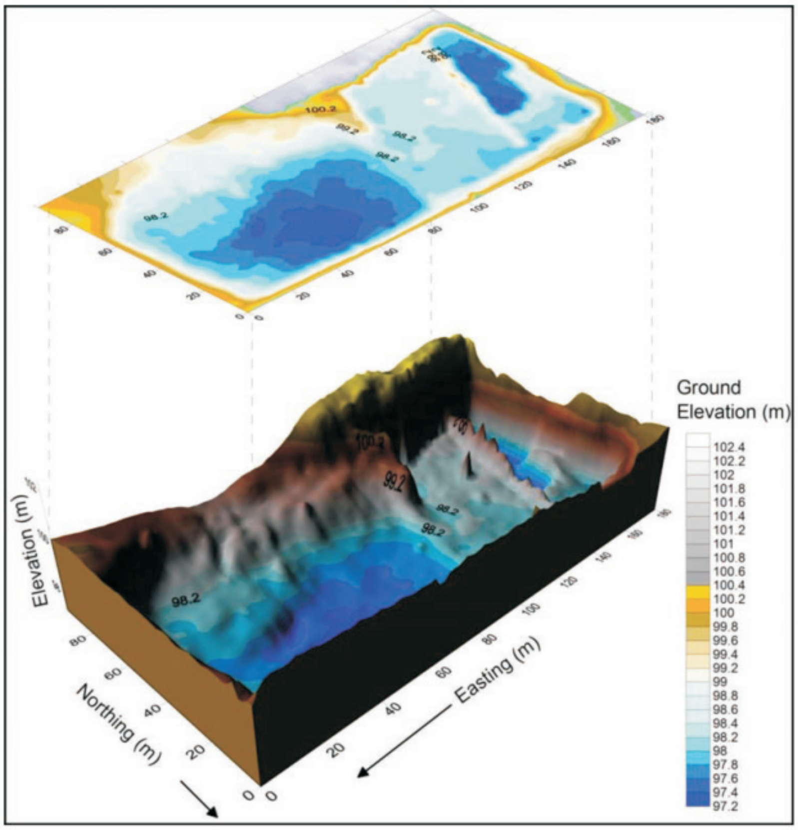

Fig. 9. Three-dimensional digital model of water reservoir

Field Crop and Seed Management to Deal with Climate, Salinity and Water Stresses

Soil carbon stock assessment under different cropping systems

Soil organic carbon (SOC) stock was assessed in 5 soil layers (0-5, 5-10, 10-20, 20-40 and 40-100 cm) under three trees (*Prosopis juliflora*, *Azadirachta indica* and *Acacia tortilis*), three grasses (*Cenchrus ciliaris*, *Cenchrus setigerus*, and *Lasiurus sindicus*) and three silvi-pastoral systems (*A. tortilis* + *C. ciliaris*, *A. tortilis* + *C. setigerus*, *A. indica* + *C. ciliaris*) along with arid horticulture and grasslands. Among trees, the highest SOC stock was observed under *P. juliflora* followed by *A. tortilis* in the top 5 cm soil layer (Fig. 10). Among grasses, SOC stock was more under *C. ciliaris* followed by *C. setigerus*. Among silvi-pastoral systems, *A. indica* + *C. ciliaris* recorded the highest SOC stock (4.24 t ha^{-1}) in top 5 cm soil layer, followed by *A. tortilis* + *C. ciliaris* (3.46 t ha^{-1}). The SOC stock showed a slight increase under all landuse systems except arid horticulture over a period of 3 years, which was statistically significant at top 0-5 and 5-10 cm soil layers in silvi-pastoral systems (Fig. 10). The significant SOC increase was also observed in 0-5 cm layer in all grasses.

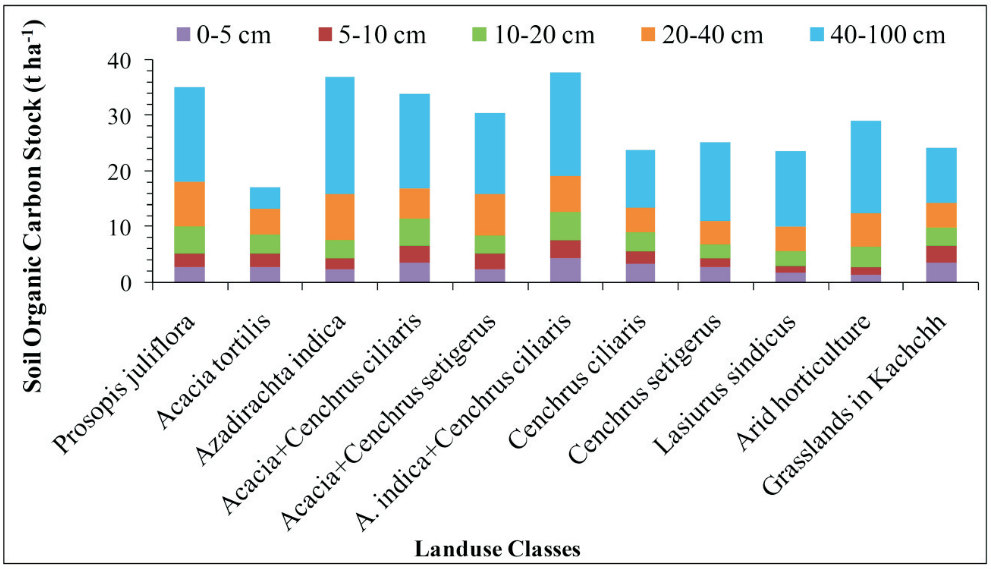

Fig. 10. Soil organic carbon stock under different cropping systems in five soil layers

Identification of high-yielding germplasms of sesame (*Sesamum indicum* L.)

Two field experiments for advance lines selection trials of sesame were undertaken during summer and kharif seasons to identify higher productive lines. A total of 51 selections of sesame, screened out from 171 germplasms, were evaluated under summer in augmented block design with the standard check GT-2. The accession NIC-8686-S2 provided the highest yield of 113.08 g m^{-2} followed by NIC-8683-S2 (104.05 g m^{-2}) while the standard check (GT-2) produced only 78.47 g m^{-2} yield. Sesame selections namely, NIC-8686-S2, NIC-8683-S3, NIC-17489-S2, NIC-8674-S1, NIC-8683-S2, NIC-8701-S1 and NIC-8678-S2 were identified as high yielders (yield $\geq$ 106.6 g m^{-2}).

Improving water productivity of field crops through deficit irrigation

Field experiments of 7 rabi season crops, i.e., wheat (GW-496), barley (RD-2552), chick pea (RG-896), mustard (GM-2), cumin (GC-4), coriander (GC-2), and fenugreek (Gujarat fenugreek-1) were undertaken under deficit irrigation using sprinkler. Irrigation was scheduled at 50% depletion of available soil moisture in 0-50 cm soil profile. The linear relationship between relative grain yield and reduced irrigation supply (% of field capacity) was found statistically significant (Fig. 11). The least reduction in grain yield under deficit irrigation at 40% of field capacity was obtained for cumin (6.5%) followed by barley (24%) and fenugreek (33%). On the contrary, wheat and chickpea were the most-sensitive crops to moisture deficit with 61.5 and 67.1% of the maximum yield produced at 40% of field capacity, respectively.

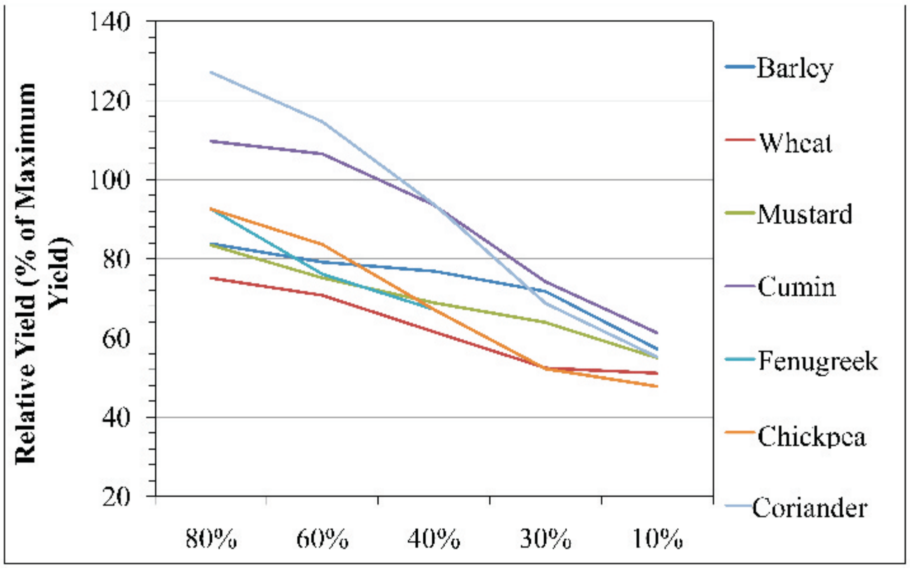

Fig. 11. Response of rabi crops to deficit water supply

Effect of Bacterial Endosymbionts and Salinity Stress on Groundnut

Two cultivars of groundnut, i.e., V1-TG-37A (susceptible to salinity) and T2-GG-2 (tolerant to salinity) were evaluated against three salinity levels namely, S0-control (no added salt), S1-saline water of 3 EC, S2- saline water of 6 EC (Fig. 12). Seeds of groundnut were treated with distilled water (T1), and with three bacterial endosymbionts, i.e., *Bacillus firmus* JN22N (T2), *B. tequilensis* (T3) and *B. subtilis* REN51N (T4). Application of *B. firmus* JN22N (T2) and *B. subtilis* REN51N (T4) improved the contents of proline, total phenol and hydrogen peroxide. The seed treatment of *Bacillus subtilis* REN51N (at 0 and 6 EC of irrigation water) and *Bacillus firmus* J22N (at 3 and 9 EC) improved the haulm yield of groundnut, although salinity × seed treatment interaction was not significant. The bacterial endosymbiont, *Bacillus subtilis* REN15N increased pod and haulm yields of groundnut by 20.5 and 21.5%, respectively up to soil salinity level of 3 dS m^{-1}. Another bacterial endosymbiont *Bacillus firmus* J22N enhanced pod and haulm yields of groundnut only under nonsaline soil, whereas, inoculation of *B. tequilensis* did not affect the yield of groundnut. Demonstrations were laid in 16 farmers' fields of Kotda and Reldi villages of Kachchh to show the beneficial effect of bacterial endophyte - *Bacillus firmus* in improving the productivity of groundnut. Groundnut seeds (cv. GG-2) were treated with *B. firmus* just before sowing and were shade-dried and sown in the field. The soils of the farmers' fields were saline (electrical conductivity of

5-6 dS m^{-1}). The pod yield in control plot ranged from 1634 to 3064 kg ha^{-1} with a mean of 2246 kg ha^{-1}, whereas it ranged from 2010 to 3403 kg ha^{-1} in treated plot with a mean value of 2685 kg ha^{-1}. The average increase in pod and halum yields due to seed treatment with bacteria over the control was 19.5 and 5.9%, respectively. The bacterial seed treatment was beneficial with net return of Rs. 63,306 ha^{-1} and benefit-cost ratio (BCR) of 2.281, against the control with net return of Rs. 49,281 ha^{-1} and BCR of 2.047.

Fig. 12. Evaluation of bacterial endosymbionts to alleviate salinity stress in groundnut

Fodder Resource Management

Evaluation and management of perennial forage legumes

Three perennial forage legumes namely, *Clitoria ternatea*, *Stylosanthes hamata* (Fig. 13a) and wild groundnut (*Arachis* Spp.) (Fig. 13b) were evaluated for their establishment, growth and fodder yields. Twenty accessions of *Clitoria ternatea* were evaluated for their growth and yield. The dry forage yield ranged from 2861 to 4606 kg ha^{-1}. The accessions CAZRI-752, JHC-94 and EC-1531-1 yielded more than 4.0 t ha^{-1}. *C. ternatea* responded significantly to the application of biofertilizers. Seed treatment with either rhizobium, phosphorus solubilizing microbes (PSM) or plant growth promoting rhizobacteria (PGPR) increased fodder yield by 3.87-20.22% over the control. The lowest yield of dry fodder (3122 kg ha^{-1}) was recorded in control. Combined application of chemical (N&P at 50% of recommended dose) and bio-fertilizer (rhizobium, PSM and PGPR) resulted in the maximum dry fodder yield of 4554 kg ha^{-1}, which was 45.9% higher than the control. The response of *C. ternatea* for dry fodder yield to Zn and Mn was linear, whereas, it was quadratic to Boron application. Soil application of Zn @ 4.5 kg ha^{-1} resulted in the maximum increase of fodder yield (53.5%), followed by Mn (52.8%) @ 3 kg ha^{-1} and B (41.3%) @ 0.6 kg ha^{-1}. Among the four species of wild groundnut namely, *Arachis glabrata*, *A. prostrata*, *A. rigonii* and *A. pusilla,* it was observed that *A. glabrata* recorded the maximum length of branches (95.5 cm) followed by *A. prostrata* (82.75 cm). The lowest branch length of 63.7 cm was recorded by *A. pusilla. Stylosanthes hamata* showed luxurious growth (height of 65 cm) having number of branches of 4.8 $plant^{-1}$ with a dry fodder yield of 3.8 t ha^{-1}.

Sorghum as Potential Fodder Resource under Salinity

Twenty-four germplasms of fodder sorghum were evaluated both in pot (Fig. 14a) and field (Fig. 14b) experiments in summer. Results exhibited considerable variability in days to 50% flowering (43-78 days), days to maturity (75-108 days), panicle length (10-43.7 cm), grain yield (580.3-3308.6 kg ha^{-1}) and stover yield (2083.3-9736.4 kg ha^{-1}). The cultivar CAZRI-FSC-3 gave the highest stover yield (9736 kg ha^{-1}) followed by CSV-15 (8769 kg ha^{-1}). Cultivars, i.e., RAJ-17, RAJ-3 and GJ-42 performed better with respect to growth and yield parameters over the remaining germplasms at higher salinity levels.

Fig. 13. Luxurious growth of (a) *Stylosanthes hamata* and (b) wild groundnut (*Arachis glabrata*)

Fig. 14(a) Pot experiment on effect of salinity on productivity of fodder sorghum
(b) Field experiment on effect of salinity on productivity of fodder sorghum

Suitable grass-legume mixture for enhancing fodder yield

A field experiment involving four grasses, i.e., *Cenchrus setigerus* (CS), *Cenchrus ciliaris* (CC), *Dichanthium annulatum* (DA) and *Sporobolus marginatus (SM)* and two legumes, i.e., *Clitoria ternatea* (CT) and *Stylosanthes hamata* (SH), as sole and 8 treatments as their intercropping with total 14 treatment combinations, was undertaken in a randomized complete block design (Figs. 15a,b). Grass-legume intercrops produced higher fresh and dry matter yields than the sole crops. Among the sole treatments, the maximum fresh herbage yield, i.e., 6669 kg ha^{-1} was recorded for DA followed by CC (4859 kg ha^{-1}). Among intercrops, DA as intercropping treatment with CT and SH recorded the maximum yield (8096 and 8040 kg ha^{-1}, respectively), which was higher than that obtained from the sole crops. Furthermore, DA+CT and DA+SH resulted the maximum crude protein yield, i.e., 685 and 668 kg ha^{-1}, respectively, which was significantly higher than that produced from other treatments. Overall, it is concluded that DA based intercrops, i.e., DA+CT and DA+SH, are the best grass-legume intercropping for enhancing quality fodder production in arid regions.

Fodder and fruit production from *Grewia* and *Cordia* species

Plants of *Grewia* species (*Grewia tenax*, *G. villosa* and *G. flavescens*) and *Cordia* species (*Cordia myxa* and *C. gharaf*) were collected from different sites in Kachchh district (Fig. 16). A total of 16 soil samples were also collected from two depths, i.e., 0-15 and 15-30 cm. Soil pH, EC, available phosphorus, potassium and organic carbon varied from 7-9,

Fig. 15 (a) *Cenchrus ciliaris* + *Stylosanthes hamata* (b) *Cenchrus setigerus* + *Clitoria ternatea*

0.09-2.71 dS m^{-1}, 0.1-5.7 kg h^{-1}, 0.1-5.7 kg h^{-1} and 0.1-0.48%, respectively. In nursery, the maximum seed germination was observed in *C. gharaf* and *G. villosa* (35% each) and the minimum in *G. flavescens* (25%). *G. tenax* took 45 days for seed germination while *C. gharaf* took only 12 days. Vegetative propagation was the most successful in *G. tenax* (70% sprouting) and the least in *C. myxa* (20% sprouting).

About 8-10 months old nursery-raised saplings of *Grewia* and *Cordia* were transplanted in field at 3 m × 3 m and 6 m × 6 m spacings, respectively. Plant survival was the highest in *C. gharaf* (>95.4%) followed by *G. villosa* (90.2%), *G. tenax* (85%) and *C. myxa* (83.33%) after 6 months of transplanting. Overall, *C. gharaf* and *C. myxa* showed better establishment and growth, while *G. villosa* showed the slowest growth. Seeds treated with aqueous solution supplemented with 2500 ppm GA_3 and 1% KNO_3, resulted in the early (4.33±0.33 days) and higher germination (79.47%). Principal component analysis of 27 *G. tenax* and 20 *G. villosa* accessions showed 75.59 and 84.13% variability, respectively, with first 5 and 6 significant principal components, respectively.

Wild forage halophytes as an alternative fodder resource under saline environment

Field surveys conducted in the Great and Little *Ranns* of Kachchh to assess the ecology and distribution of halophytes indicated dominance of halophytes such as *Aeluropus lagopoides, Cressa cretica, Suaeda nudiflora* and *Urochondra setulosa* under extreme saline environments (soil salinity ~ 0.32 - 64 dS m^{-1}). Samples of *Cressa cretica* collected from three sites at 15 days intervals showed a wide variation among sites and sampling dates. The highest organic matter (OM) content was observed in stems,

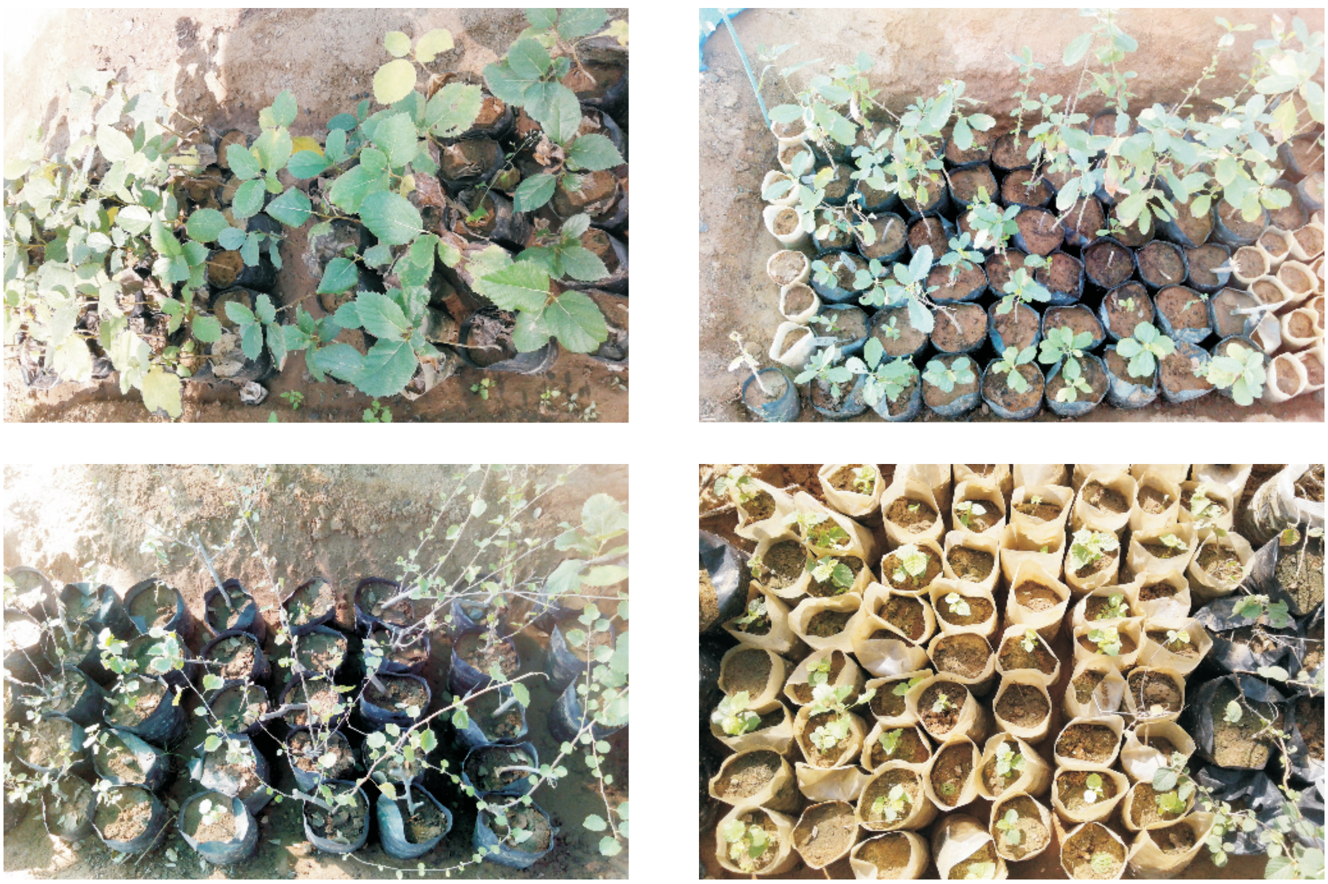

Fig. 16. Nursery plantation of (a) *Cordia myxa*, (b) *Cordia gharaf*, (c) *Grewia tenax* and (d) *Grewia villosa*

followed by root and the lowest was in leaves. The total ash, silica and Ca concentration was highest in leaves and lowest in stem. No variation was observed in P concentration. The Ca and P content of *C. cretica* was more than the recommended dietary level of cattle and sheep. With increase in salinity, OM decreased and silica content increased. At higher salinities, initial harvest provided quality fodder.

The less salinilty-tolerant grasses like *Dichanthium annulatum* attained faster maturity after flowering (400 degree days), followed by *S. marginatus* (600 degree days), *U. setulosa* (1300 degree days) and *A. lagopoides* (1400 degree days), while *S. nudiflora* attained maturity in 450 degree days. The colour at maturity was brown for *D. annulatum*, yellowish white for *S. marginatus*, brownish white for *A. lagopoides*, brown for *U. setulosa* and brown for *S. nudiflora.*

Pot culture experiment with six salinity treatments, i.e., 0, 20, 40, 60 and 80 dS m^{-1}, on eight weeks old plants was undertaken. In order to avoid the sudden osmotic shock, 5 dS m^{-1} of salt was added daily. The results indicated that among four halophytes (*U. setulosa*, *A. lagopoides*, *C. cretica* and *S. marginatus*), the shoot biomass was higher for *U. setulosa* followed by *S. marginatus*, whereas root biomass was higher for *S. marginatus*. Initial increase in salinity was found to enhance dry matter, which decreased at higher salinity levels. The grasses viz., *D. annulatum* and *Cenchrus ciliaris* could not grow at salinity levels of 20 EC and above.

In pot culture studies at 90 DAS, the major ion excreted through leaves was sodium followed by potassium. Leaf wash of *U. setulosa* contained highest sodium (62.4 meq L^{-1}) recorded at 40 dS m^{-1}. The osmoprotectant glycine betaine linearly increased in *U. setulosa* with increase in salinity (0.0127 to 0.2755 mg g^{-1}). In *A. lagopoides*, the content of Superoxide dismutase linearly increased with salinity (0.3715 to 0.8408 mg g^{-1}).

Nutrient Management in Palatable Halophytes for Augmenting Fodder Resources

Four palatable halophytes namely, *Aeluropus lagopoides, Cressa cretica, Suaeda nudiflora* and *Sporobolus marginatus* were collected from the Great and Little *Ranns* of Kachchh and evaluated for growth and fodder yields. In nursery, *A. lagopoides* had the maximum number of tillers $plant^{-1}$ (100.4) followed by *S. marginatus* (62.4). *C. cretica* had the lowest branches $plant^{-1}$ (6.20). *S. nudiflora*, a dicot halophyte, had the maximum fresh weight (110.40 g $plant^{-1}$) followed by *Sporobolus* (77.40 g $plant^{-1}$). However, *A. lagopoides*, a grass halophyte, had the maximum dry weight (65.00 g $plant^{-1}$), followed by *S. marginatus* (57.6 g $plant^{-1}$). *C. cretica* had the lowest fresh weight of 11.53 g $plant^{-1}$ and dry weight of 3.94 g $plant^{-1}$. Plant height increased significantly and number of branches per plant decreased with increase in plant density, irrespective of type of halophytes. Green and dry fodder yields were significantly influenced for *C. cretica* and *A. lagopoides*, where an increase in plant density from 1.11 to 2.22 ha^{-1} increased green fodder yield by 85.61 and 84.22%, respectively and dry fodder yields by 31.13 and 30.55%, respectively. Fodder yield of *Suaeda* spp. and *Sporobolus* spp. was not influenced by change in plant density.

Application of K (90 kg K_2O ha^{-1}) significantly improved growth and fodder yield of halophytes. Response of fodder yield of grass halophytes, i.e., *A. lagopoides* and *S. marginatus*, to K application was linear ($r^2 \geq 0.90$); however, the response of non-grass halophytes, i.e., *C. cretica and S. nudiflora*, was quadratic ($r^2 \geq 0.879$) where dry fodder yield increased up to K application of 60 kg ha^{-1} and further K addition decreased fodder yield. Application of four levels of N and P was considered in two halophytes, i.e., *A. lagopoides* and *S. marginatus*. In *A. lagopoides* and *S. marginatus*, the highest green fodder yield (5.13 and 5.82 t ha^{-1}, respectively) was recorded at 150 kg ha^{-1} of N, while at 100 kg ha^{-1} of N, it was 4.64 and 5.76 t ha^{-1}, respectively. Application of P could not reveal any significant differences in green fodder yield. The highest interaction effect of N and P on green fodder yield of *S. marginatus* was found with N150-P60.

Cactus Pear (*Opuntia ficus-indica*) as livestock fodder: Establishment and evaluation

Field establishment of 33 accessions of cactus pear (Fig. 17) showed 50-100% survivability with 1 to 11 cladode production in 4 months after transplanting. Among the 33 clones, the clone nos. 1270, 1271, 1287, 1308 and clones seedless Santa Margherita Belice, Blue Motto, Seedless Roccapalumba and Morado exhibited vigorous growth under field conditions. In nursery (Fig. 18), out of 39 accessions, 37 exhibited 100% survivability and two failed to survive. Cladode area per plant was highest for Gymnocarpe (354.9 cm^2), followed by Clone no. 1287 (345.9 cm^2) and least for Red Santa Margherita Belice and Piantra 25. Six accessions, namely, 1270, 1271, 1308, 1287, Bianco Macomer and CAZRI Botanical Garden (CBG), identified as higher fodder yielders, were further multiplied in 1.5 ha area and distributed to the farmers and ICARDA, India centre.

Fig. 17. Field establishment of 33 accessions of cactus pear

Fig. 18. Nursery multiplication of cactus pear

Fodder supply from agroforestry system: Cactus-based three-tier model

A cactus-based three-tier agroforestry system consisting of two trees (*Salvadora oleoides* and *Prosopis cineraria*), three cactus pear accessions (CAZRI Botanical Garden, Clone 1308 and Bianca Macomer) and two grasses (*Dichanthium annulatum* and *Sporobolus marginatus*) was established. The average plant growth of *P. cineraria* in terms of plant height, collar diameter and number of branches was higher than that in *S. oleoides*. The average height and number of tillers were higher in *D. annulatum* than that in *S. marginatus*. The average tussock diameter was high in *S. marginatus* compared to *D. annulatum*. After two years of planting, the average green and dry fodder yields were 14.18 and 7.33 kg ha^{-1}, respectively for *P. cineraria* and 230.53 and 113.91 kg ha^{-1}, respectively for *S. oleoides* (Fig. 19). Among cactus accessions, CAZRI Botanical Garden produced the maximum green fodder yield (6.5 t ha^{-1}) followed by Bianca Macomer (3.3 t ha^{-1}) and clone 1308 (2.9 t ha^{-1}). The green and dry fodder yields of *S. marginatus* were 4.0 and 2.4 t ha^{-1} while *D. annulatum* yielded 1.9 and 1.3 t ha^{-1}, respectively. Overall, *S. oleoides* + CAZRI Botanical Garden + *S. marginatus* based agroforestry system yielded the maximum green (10.95 t ha^{-1}) and dry fodder (3.04 t ha^{-1}) whereas *S. oleoides* + Clone 1308+ *D. annulatum* system produced the minimum green (4.41 t ha^{-1}) and dry fodder yields (1.96 t ha^{-1}).

Promoting Cactus pear (*Opuntia ficus-indica*) as drought resilient feed resource

Cactus pear has been evidenced to be a potential feed resource for livestock in arid climate of Gujarat through evaluation of 64 accessions maintained at the station. Based on field evaluation, 5 accessions, viz., Clone-1308, Gymnocarpe, Bianca Macomer, CAZRI Botanical Garden (CBG) and CAZRI Kukma were identified as high fodder yielding accessions. Fruits of cactus pear contained higher amounts of antioxidants and essential amino acids than that available in the wild cactus pear. It is observed that cactus pear responds faster to organic manures than inorganic

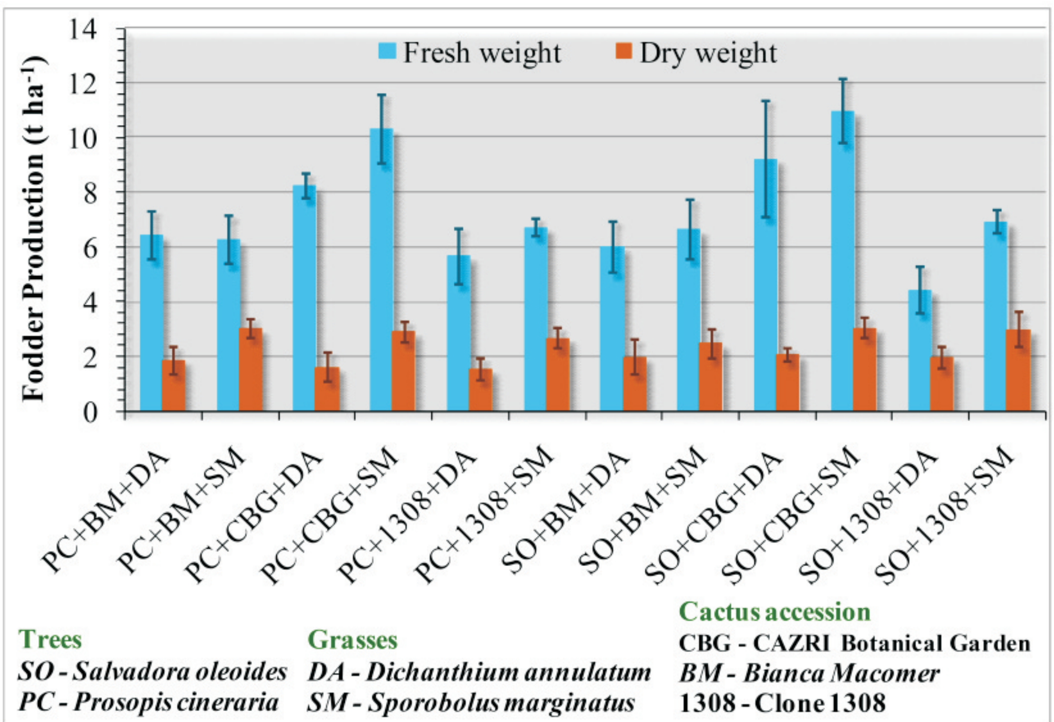

Fig. 19. Green and dry fodder yields of cactus-based three-tier agroforestry models

fertilizers, while August-September is the best time for planting cactus in Kachchh region. Since 2017, a total of 4150 cactus cladodes have been distributed to 42 farmers in 34 villages, one non-governmental organization and three government agencies (Fig. 20).

Fig. 20. Monitoring of cactus plantation at farmer's field in Zinkani village, Bhuj

Impact of Climate Change in Agriculture, its Adaptation and Mitigation Strategies

Understanding Rainfall Dynamics in Kachchh Region

Dynamics of 34-year (1980-2013) annual rainfall for ten talukas in Kachchh district was explored by identifying 5 characteristics, i.e. normality, stationarity, homogeneity, presence/absence of trend, and persistence. Box-whisker plots, normal probability plots and histograms indicated that rainfall in Mandvi and Dayapar talukas is more positively-skewed compared to other talukas, due to the presence of outliers and extremes. Shapiro-Wilk and Lilliefors tests revealed that rainfall of all talukas deviated significantly from normal distribution. The t-tests and Mann-Whitney test indicated non-stationarity and non-homogeneity in rainfall of Rapar taluka. Four trend tests indicated significantly increasing trends of rainfall in Rapar and Gandhidham talukas (Fig. 21). Persistence was statistically-significant in rainfall of Bhachau (3-year), Mundra (1- and 9-year), Nakhatrana (9-year) and Rapar (3- and 4-

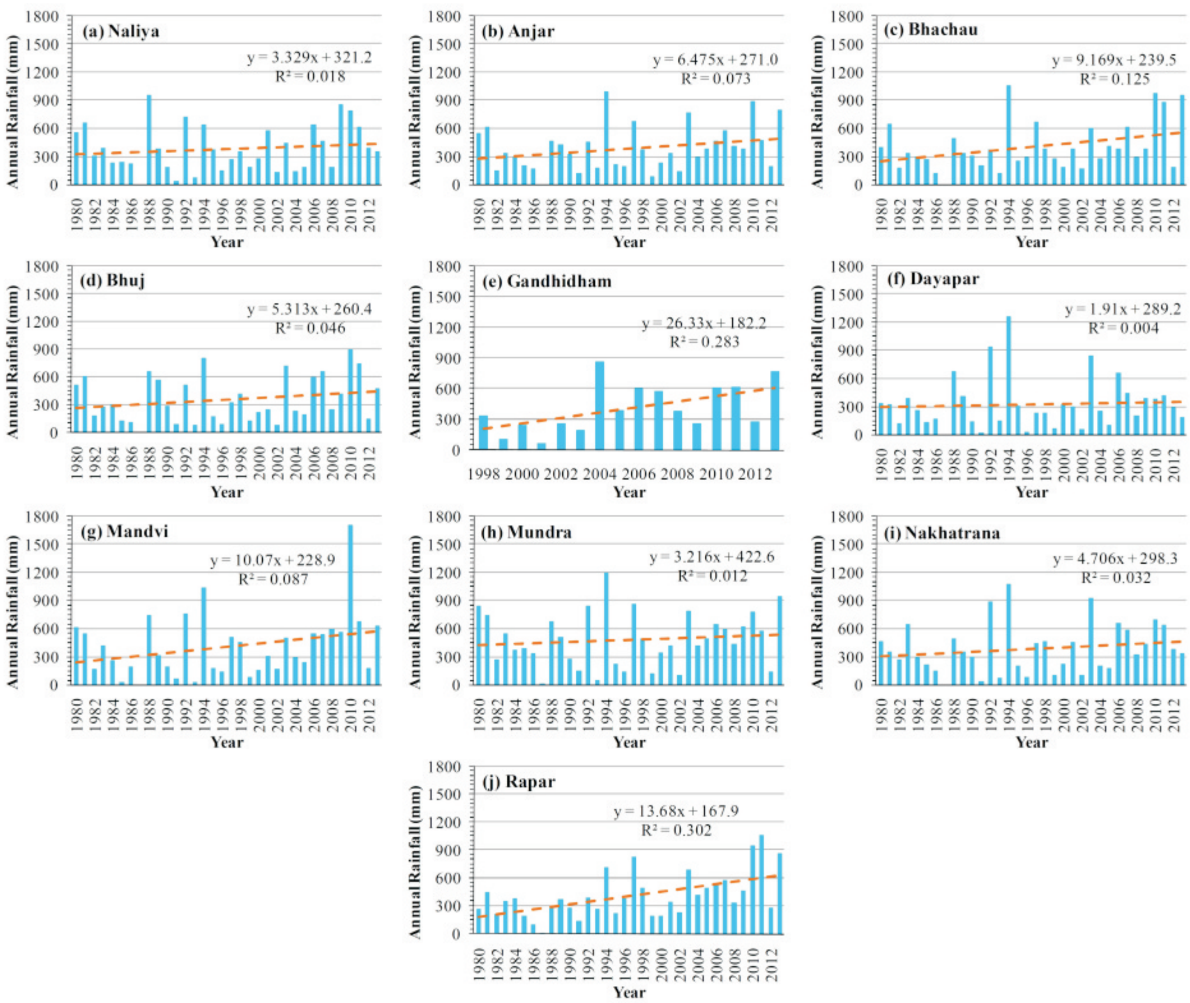

Fig. 21. Barcharts of rainfall showing presence of linear trend, regression equation and coefficient of determination (R2) values

year). Based on sustainability approach, rainfall of Mundra and Naliya talukas (reliability ≥ 0.50 and 0.44; resilience ≥ 0.47 and 0.47; vulnerability ≥ 0.49 and 0.46, respectively) were the most sustainable and dependable compared to other talukas. The highest sustainability index in Mundra (0.120) and Naliya (0.112) talukas further confirmed the findings. Overall, rainfall in Kachchh district is less reliable, less resilient and moderately vulnerable, which emphasizes the need of developing strategies for sustainable water resources management.

Significant Rising Trends in Rainfall and Temperature Series

Trends in 35-year (1979-2013) temperature (maximum, T_{max} and minimum, T_{min}) and rainfall (Fig. 22) at annual and seasonal (pre-monsoon, monsoon, post-monsoon and winter) scales were investigated for 31 grid points in Kachchh region. Modified Mann-Kendall (M-K) test indicated significantly increasing trends in T_{min}, which are more prominent than T_{max}. Sen's slope test suggested that both the annual and monsoon rainfall have a significantly increasing trend of 9 mm year^{-1}. The sequential trend significance in M-K test-statistics was very strong (R^2≥0.90) in annual and pre-monsoon T_{min} (90% grid points), and strong (R^2≥0.75) in monsoon T_{max} (68% grid points), monsoon, post-monsoon and winter T_{min} (65, 55 and 48% grid points, respectively), as well as in annual and monsoon rainfall (68 and 61% grid points, respectively). It was emphasized that rising T_{max} may hinder crop growth due to enhanced metabolic-activities and shortened crop-duration. Likewise, increased T_{min} may result in lesser crop yields and biomass owing to increased respiration over photosynthesis. Hence, appropriate measures need to be undertaken to safeguard the crop production against the rising temperatures.

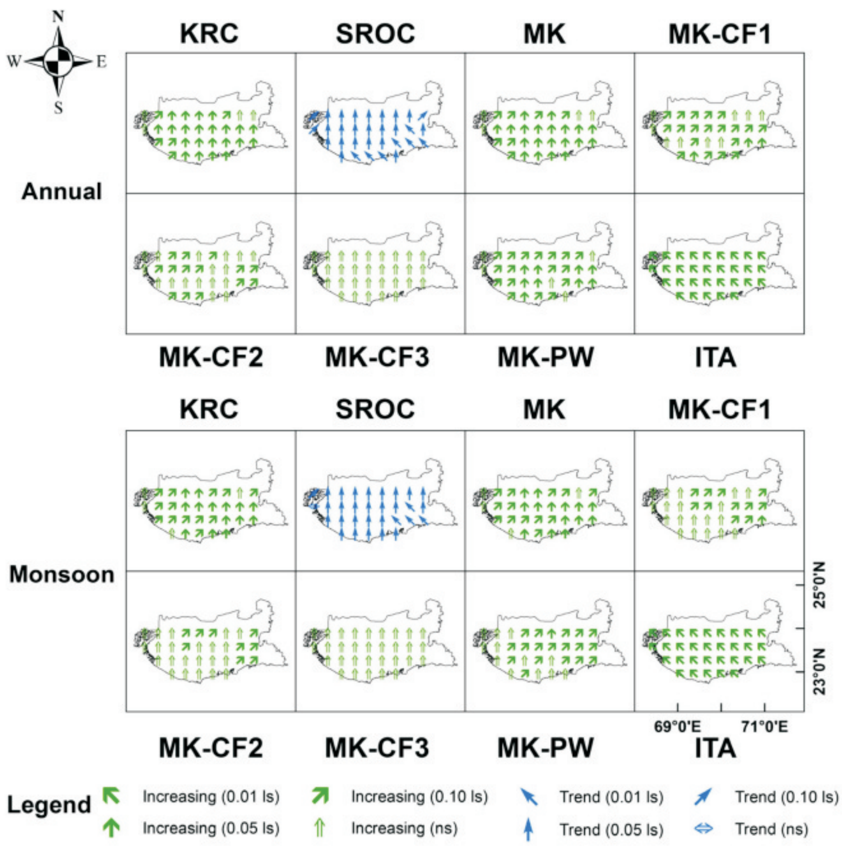

Fig. 22. Results of eight trend tests showing significant and non-significant (ns) increasing/decreasing rainfall trends

Occurrence of significant change points in annual rainfall over Kachchh region

Abrupt change points (CPs) were identified in 34-year (1980-2013) annual rainfall of nine talukas of Kachchh region. The CPs identified by Standard Normal Homogeneity test and cumulative deviations test were similar at most of the talukas. On the contrary, Pettitt and Bayesian tests detected significant CPs in years 2002 and 2005 in 6 and 3 talukas, respectively. The mean annual rainfall after CPs (350-627 mm) increased by 14-80% of the amount before CPs (306-444 mm) with 7-42% reduction in coefficient of variation (Fig. 23). M-K test indicated significant rainfall trends at Anjar, Bhachau, Mandvi, and Rapar. Trend magnitudes prior to CPs (6.2-7.1 mm $year^{-1}$) showed an overall increase after CPs (4.7-40.8 mm $year^{-1}$) with negative trend in one taluka. Sen's slope test revealed that trend magnitudes after CPs were 2-10 times higher than that for entire period in 6 talukas. The M-K test over sequential periods emphasized stronger rainfall trends over time, which indicates that significance level of rising rainfall trends may further enhance in future. Overall, adequate policies need to be developed to meet the challenges of the heightened rainfall in Kachchh region.

Evaluating temporal stability of rainfall spatially over Kachchh region

A Stability Index (SI) was developed to evaluate long-term rainfall stability at 36 gridded points in Kachchh region using probabilistic indicators namely Reliability, Resilience and Vulnerability (RRV) and geostatistical modeling (Fig. 24). The 'low' to 'moderate' range of Reliability (0.29-0.49), Resilience (0.27-0.50) and Vulnerability (0.35-0.49) suggested that the rainfall was at a high risk of having insufficient water. The scatter plots of RRV indicators and coefficient of variation, Spearman's rank correlation and Student's t-test revealed that SI precisely accounted for the long-term stability of the annual rainfall. The SI was found superior to the traditional measures of dispersion as the former addresses risk in terms of frequency of being higher than the mean rainfall and considers ability to return from the unsatisfactory to satisfactory condition. The findings can be useful to solve future rainwater management problems under changing climatic conditions by delineating prioritized areas spatially.

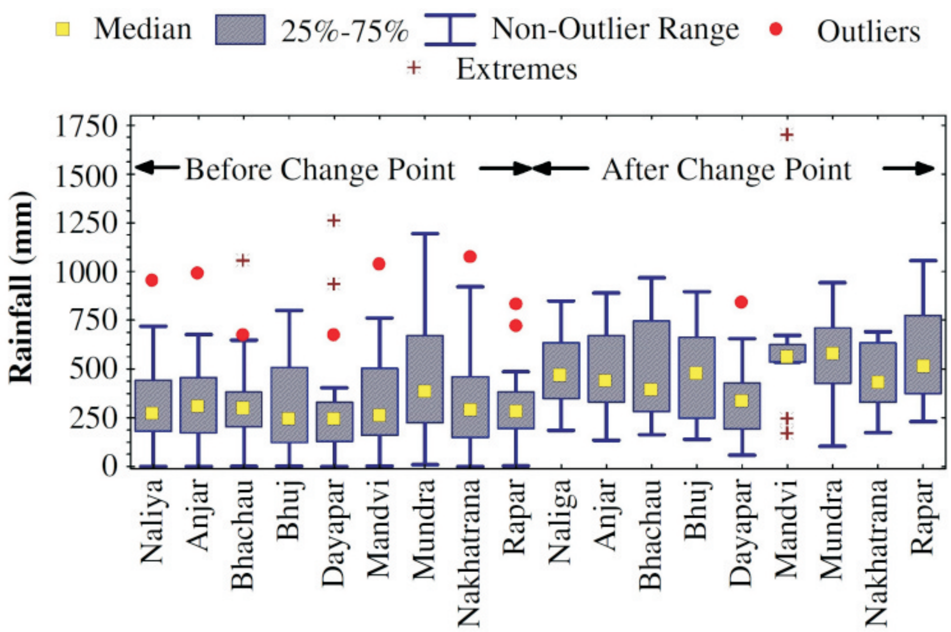

Fig. 23. Box-whisker plots of annual rainfall for nine talukas of Kachchh district before and after change points

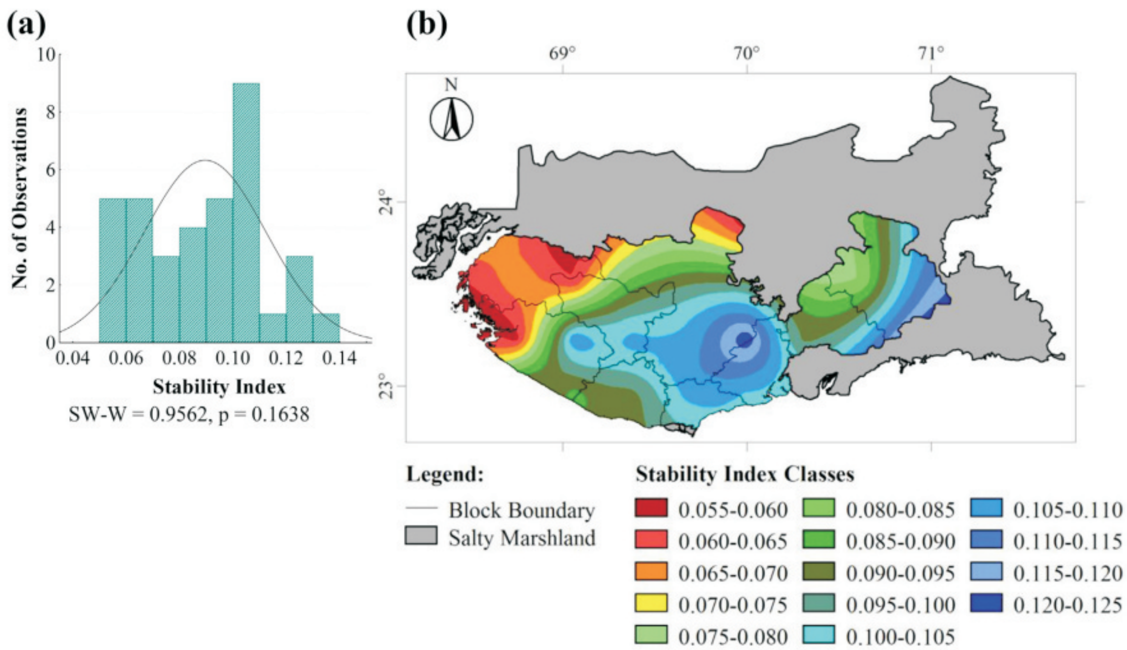

Fig. 24. (a) Histogram of rainfall Stability Index and test-statistics of Shapiro-Wilk (SW-W) test and (b) spatial distribution of rainfall Stability Index over Kachchh region

Dynamics of spatially-distributed groundwater levels

Dynamics of 22-year (1996-2017) pre and post-monsoon groundwater levels in Kachchh region were explored by examining stationarity, persistence, trend and homogeneity. A novel framework was developed by integrating time series modeling and geostatistical modeling with geographic information system for applying statistical tests to spatial (raster) dataset. Non-stationarity in groundwater levels was found significant in Bhuj, Mundra, Nakhatrana, and Abdasa talukas, which increased from 48% area in pre-monsoon to 62% area in post-monsoon. Persistence was not found in pre- and post-monsoon groundwater levels ($p>0.01$). Mann-Kendall test indicated that significantly increasing trends were more prominent in post-monsoon (64% of area under increasing trends) than that in pre-monsoon (47% of area under increasing trends). The rising groundwater levels were mostly recorded in Bhuj, Mundra, Nakhatrana, Anjar, and Bhachau blocks, which were attributed to occurrence of significant change points in annual rainfall that enhanced groundwater recharge. These areas were safer for groundwater extraction in comparison to that in Rapar taluka, where groundwater levels were declining.

Climate change adaptation through water and livelihood security and ecosystem restoration

In Banni grasslands, a total of 80 soil samples were collected from seed bank plot near Gorewali village and analyzed for chemical parameters. Soil was found saline/alkaline with pH values ranging from 7.31 to 9.30 and EC from 0.17 to 4.67 dS m^{-1}. Soils in eastern part of Banni had high pH and low EC; however, low pH and high EC were recorded in western part. Preliminary studies conducted in nursery (0.2 ha) of the station revealed the maximum dry fodder production of potential fodder species, viz. *Cenchrus ciliaris* (3.6 t ha^{-1}), *Sporobolus marginatus* (2.9 t ha^{-1}), *Dichanthium annulatum* (2.3 t ha^{-1}), *Aeluropus lagopoides* (2.4 t ha^{-1}), *Cenchrus setigerus* (1.9 t ha^{-1}), *Suaeda nudiflora* (1.8 t ha^{1}) and *Cressa cretica* (1.2 t ha^{-1}). Based on fodder production and palatability, four species namely *C. ciliaris, S. marginatus, D. annulatum* and *C. setigerus* were selected for large-scale seed production. Nursery beds for the selected grasses and perennial forage legume, i.e., *Clitoria ternatea*, suitable for production in Banni area were established in 4 ha area at station. Grass seeds were supplied to District Forest Department for restoration of area in three villages of Banni grasslands, viz. Gorewali, Hajipir and Burkal.

Agrivoltaic System: A twin way for energy and agriculture

Solar photo-voltaic system with a total capacity of 25 KW was installed at agricultural farm of the station. Three kharif crops namely, clusterbean, mung bean and moth bean and four rabi crops namely, cumin, fenugreek, isabgol and ajwain were grown in the space between the panels (Fig. 25). In addition, four medicinal crops namely, aloevera, senna, ashwagandha and shankhpushpi, were also grown in the space below the panel. Among the kharif crops, moth bean was found more remunerative with net return of Rs. 22,292 ha^{-1} and benefit-cost ratio (BCR) of 1.84, followed by mung bean (net returns of Rs. 18,695 ha^{-1} and BCR of 1.84). In rabi crops, isabgol gave the maximum net return of Rs. 81,880 ha^{-1} with a BCR of 3.14, followed by cumin (net return of Rs. 61,073 ha^{-1} and BCR of 2.58). Among medicinal crops, shankhpushi was found as the most beneficial with the maximum net return of Rs. 1,74,675 ha^{-1} and BCR of 6.53, followed by aswagandha (net return of Rs. 1,55,017 ha^{-1} and BCR of 6.35) and senna (net return of Rs. 39,240 ha^{-1} with BCR of 2.23).

Impact of landuse and management on soil quality in Kachchh region

Soil organic carbon (SOC), an important parameter in soil functioning and greenhouse gas exchange with atmosphere, is vital for developing strategies dealing with mitigation and adaptation to climate change impacts in agriculture. The SOC content was determined in salient landuse systems of Bhuj taluka of Kachchh region as landuse and its changes may critically affect the SOC. Soil samples (0-30 cm depth) were collected from 9 landuse systems, i.e., (a) protected forest (established during 2010-11), having *Commiphora wightii* as the major plant species, (b) openly-grazed area having mostly native grasses such as *Dichanthium annulatum,* (c) fodder cactus pear field (>5 years), (d) castor crop

Fig. 25. A view of solar photo-voltaic system of 25 KW capacity along with crops between and beneath panels

(>15 years), (e) pomegranate orchard (>10 years), (f) wheat crop (>15 years), (g) cultivated pasture crops (>5 years) with Napier and lucerne, (h) date palm orchard (>15 years), and (i) fallow land as control. The maximum SOC was found in protected forest (1.28 g kg^{-1}) and cultivated pasture (1.25 g kg^{-1}), while it was minimum in control (0.45 g kg^{-1}) (Fig. 26). Landuse systems arranged in order of decreasing SOC content are: protected forest > cultivated pasture > openly-grazed land > pomegranate orchard > castor crop > date palm orchard > cactus field > wheat crop > control (Fig. 26). Soils under arable crops showed lesser SOC due to intensive farming practices that led to fast oxidation and loss of SOC. Electrical conductivity (EC) was found to be negatively correlated to SOC ($p<0.05$), indicating the effect of higher salt content that could lead to lower biomass production and lesser SOC.

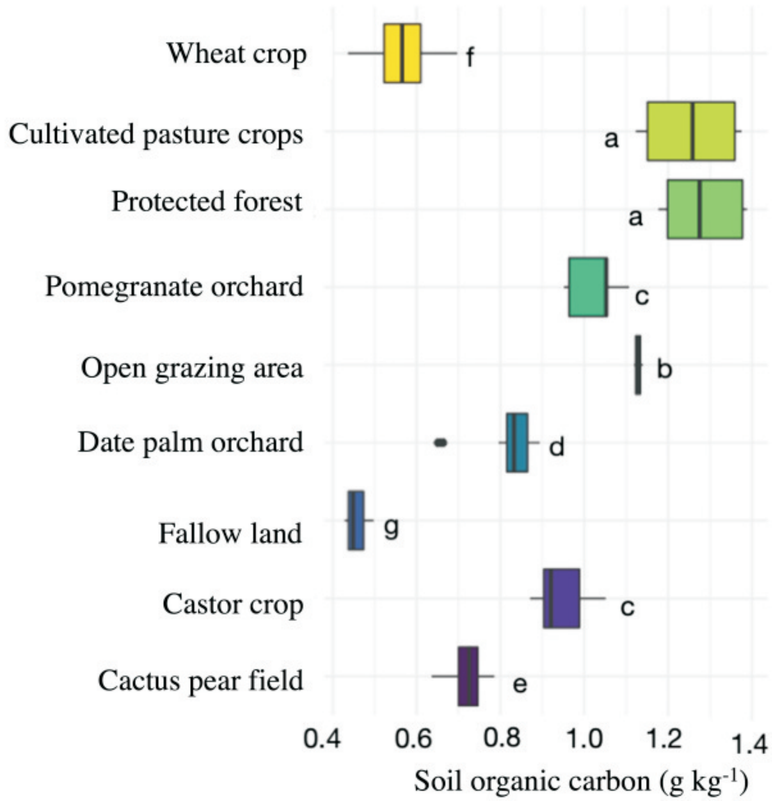

Fig. 26. Soil organic carbon content in landuse systems of Bhuj taluka

Socio-Economic Evaluation: Livelihood Analysis of Pastoralists (Maldharis) in Banni Grasslands of Gujarat

Sustainability of livelihood options for pastoralists (*Maldharis*) in Banni grasslands

A socio-economic survey of 280 pastoralist (*Maldharis*) households in 12 villages of Banni grasslands was conducted to understand occupational patterns adopted to sustain livelihood in harsh climate and saline environment. Maldharis are landless livestock rearers who depend on gauchars for their livestock rearing. A total of 11 distinct livelihood options in Banni grasslands were: (a) Banni buffalo based pastoralism, (b) goat and sheep rearing, (c) *Prosopis juliflora* based charcoal production, (d) honey collection, (e) gum extraction, (f) embroidery, (g) leather work, (h) labour, (i) services, (j) tourism and (k) trade. Pastoralism was the major primary occupation for 70% households, whereas charcoal production was the major secondary occupation for 60% households. Contribution of primary occupation to annual income ranged from 38 to 93%, whereas secondary occupation(s) contributed from 0.3 to 42%. The sustainability of these livelihood options was the highest for buffalo rearing based on ecological, economic and socio-cultural indicators on a scale consisting of 18 indicators. Economic sustainability of charcoal production was higher than that of goat and sheep rearing, whereas the ecological and socio-cultural sustainability of the latter was higher. Migratory pastoralism employed 70% households and generated the highest revenues to individual households that ultimately contributed to the economy of Banni grassland. Goat and sheep rearing, being more sustainable, could provide an alternative to charcoal production, which is an adaptation strategy for livelihood security. Scientific management of rapidly expanding *P. juliflora* is crucial for conservation of Banni ecology and improving livelihoods.

Growth and Variation of Livestock Species in *Banni* Grasslands

Livestock population analysis (1977-2012) in Banni grasslands revealed that compound annual growth rate (CAGR) for Banni buffaloes (5.89%) was highest followed by Kankrej cattle (1.78%), whereas CAGR was negative for goat (-0.29%) and sheep (–0.28%) population (Fig. 27). Cuddy Della Valle Instability Index was very high for goat (89%) and sheep population (78%), whereas, it was low for buffaloes (31%) and cattle (23%). Drought duration and severity significantly influenced the population of

Fig. 27. (a) Banni buffaloes (b) Kankrej and Sahiwal cattle

goat and sheep. However, shift in buffalo and cattle population was affected by complex technological and policy factors. Decline in demand of Kankrej bullocks for agriculture use, low milk productivity of cows, and detrimental impact (weakening and dislocation of jaws and gradual death of cows) of regular feeding on *Prosopis juliflora* pods led to significant decrease in population of Kankrej cattle when compared to Banni buffaloes. Population growth rate of Banni buffaloes (457%) was six times higher than that of Kankrej cows (70%). Composition of different livestock species (buffaloes: 72%, cattle: 16%, goat: 7% and sheep: 6%) revealed dominance of Banni buffalo both in terms of number and contribution to livelihood of pastoralists and overall economy of Banni grasslands.

Outreach

Farmers' Trainings/Farmer Fair/Field Day/Kisan Goshthi/Farmer-Scientist Interaction Meeting/ Awareness Programme

Date	Name of program	No. of trainees
January 17, 2012	Farmers Training on Feed and Fodder Management for Profitable Animal Husbandry	400
February 24-25, 2012	Farmers Training-cum-Seminar on Production Technology of Pomegranate	300
September 29, 2012	Farmers' Fair	400
January 16-18, 2013	Farmers' Fair and Farmer-Scientist Interaction Program	3000
December 13, 2013	Awareness-cum-Training Program on Protection of Plant Varieties & Farmers' Right sponsored by Protection of Plant Varieties & Farmers' RightS (PPV&FR) Authority, Ministry of Agriculture, Government of India, New Delhi	150
January 16, 2014	Training on Protection of Plant Varieties & Farmers Right sponsored by Protection of Plant Varieties & Farmers Right (PPV&FR) Authority, Ministry of Agriculture, Government of India, New Delhi	100
January 17, 2014	Farmers' Fair	350
February 24, 2015	Training-cum-Awareness on Protection of Plant Varieties and Farmers' Right Act 2001 sponsored by Protection of Plant Varieties & Farmers' Right (PPV&FR) Authority, Ministry of Agriculture, Government of India, New Delhi	200
March 03, 2015	Field Day on Thornless Cactus sponsored by ICARDA	90
October 09, 2015	Field Day on Cactus Pear (*Opuntia ficus-indica*) sponsored by ICAR-ICARDA Collaborative project	50
March 27, 2017	Krishi Mela sponsored by RKVY/ ATMA, Bhuj	250
January 21, 2017	Farmers'-Scientist Interaction program sponsored by ATMA, Bhuj	70

Exhibitions Conducted/Participated

Date	Nature of activity	Occasion	Place
December 31, 2015	Rabi Krishi Mahotsav in Bhuj taluka	Exhibition	Bekariya *Rann*, Bhuj
May 23-24, 2016	Agriculture Exhibition and Farmer's Scientist Interaction Program	Krishi Mahotsav	Bhachau
May 27-28, 2016	Agriculture Exhibition and Farmer's Scientist Interaction Program	Krishi Mahotsav	Bhuj
March 27, 2017	Exhibition-cum-Scientist and Farmer's Interaction	Agricultural Fair	RRS, Bhuj

Radio Talks

Radio channel	Date of broadcast	Topic of talk	Name of scientist
All India Radio, Bhuj	June 17, 2015	जल संरक्षण	Deepesh Machiwal
All India Radio, Bhuj	July 01, 2015	फसलों में पोषक तत्व प्रबंधन	Sushil Kumar
All India Radio, Bhuj	September 02, 2015	अनियमित वर्षा में अधिकतम फसल उत्पादन	Devi Dayal
All India Radio, Bhuj	October 19, 2016	पारंपरिक वर्षाजल का संग्रह	Deepesh Machiwal
All India Radio, Bhuj	July 19, 2017	वर्षाजल का उचित प्रबंधन	Deepesh Machiwal

Details of On-Campus and Off-Campus Trainings for Farmers

Year	On-campus		Off-campus	
	Courses	Trainees	Courses	Trainees
2014	11	236	23	867
2015	5	119	29	834
2016	8	192	31	724
2019	19	626	34	807

Farmers' Training on Feed and Fodder Management for Profitable Animal Husbandry on January 17, 2012
Farmers' Fair and Farmers'-Scientist Interaction Program during January 16-18, 2013

Visit of DDG (Agril. Extn.) Dr. K.D. Kokate, ICAR, New Delhi in Farmers Fair on January 18, 2013

Training Program on Protection of Plant Varieties & Farmers Right on January 16, 2014
Glimpses of Field Day on cactus sponsored by ICAR-ICARDA collaborative project, organized at the station on March 03, 2015

Institute Development

RRS, Bhuj of ICAR-CAZRI has undergone various developmental activities over the decade 2011-2020 including purchase of many farm implements, equipments, laboratory instruments and other building infrastructure. More than ten large capacity farm implements were added to the station assets such as tractor, thresher, trolley, rotavator, cultivator, scraper blade, fodder block machine, mini cultivator, scraper, water tanker, tractor-drawn auger, multi-crop thresher, hydraulic tractor trolley, mist blower-cum-duster etc. for improving agricultural operations. Also, experimental research laboratory of the station has been upgraded with procurement of several high precision and advanced instruments, viz. atomic absorption spectrophotometer, combined and furnace spectrophotometer, double beam PC-based UV VIS spectrophotometer, seed germinator, compound research microscope, centrifuge, balance, electronic top palm balance, hot air oven, laboratory water bath, magnetic stirrer with hot plate, wet sieve shaker, digital salinity meter, digital water-level recorder, single-phase voltage stabilizer, water purification system, vacuum pump, refrigerator, alpha platform type rotary shaker, global positioning system (GPS), muffle furnace, EC meter, hot plate, pH meter etc. for improving the quality of research as well as to provide soil and water testing facilities to the farmers.

Besides these, following infrastructure was developed during 2011-2020.

- Development of a seed house
- Expansion of farm pond
- Renovation of office building
- Repair of farm road
- Construction of farm seed store
- Replacement of old and damaged lighting cable with new cable
- Establishment of implement shed near farm section of the station
- Partitioning of farm section building into three glass compartments
- Construction of concrete blocks under externally-funded project on Understanding the adaptation mechanism of wild forage halophytes in the extreme saline-sodic Kachchh plains for enhancing feed resources
- Renovation of newly developed laboratory by providing false ceiling and tiling
- Construction of library-cum-conference hall at first floor
- Installation of diesel-operated electricity generator
- Installation of 30 kW capacity land-based solar photovoltaic (PV) panels system with performance evaluation system, component 2-25 kW on grid tied solar PV system
- Installation of a tubewell within the campus of the station

Linkages and Collaborations

Linkages and collaborations were established with the following agencies.

- International Centre for Agricultural Research in the Dry Areas (ICARDA), Jordan
- ICAR-Central Soil Salinity Research Institute, Karnal
- ICAR-Indian Grassland and Fodder Research Institute, Jhansi
- ICAR-Directorate of Groundnut Research, Junagadh
- Indian Institute of Remote Sensing, Dehradun
- Date Palm Research Institute, Mundra
- Gujarat Institute of Desert Ecology (GUIDE), Bhuj
- Sardarkrushinagar Dantiwada Agricultural University (SDAU), Gujarat
- Anand Agricultural University, Anand
- Krantiguru Shyamji Krishna Verma Kachchh University, Bhuj
- Krishi Vigyan Kendra (KVK), Mundra, Kachchh
- State Department of Agriculture, Bhuj
- District Watershed Development Unit (DWDU), Bhuj
- State Department of Forest, Bhuj
- GEER Foundation, Gandhinagar, Gujarat
- Agricultural Technology Management Agency (ATMA), Bhuj

Meetings and Events Organized

National Level Workshop/Symposium/ReviewMeeting Organized

Date	Name of workshop/symposium and venue	Organizers
December 20-22, 2011	National Symposium on Resource Utilization through Integrated Farming System and Biodiversity Conservation in Drylands	AZRAI, Jodhpur and ICAR-Central Arid Zone Research Institute, Jodhpur
February 26-28, 2013	National Workshop on *Prosopis juliflora*: Retrospect and Prospects at CAZRI, RRS, Bhuj	NAIP Project, ICAR-Central Arid Zone Research Institute, Jodhpur and ICAR-CAZRI, RRS, Bhuj
January 16-18, 2017	National Review Meeting on Cactus Pear	ICAR-Central Arid Zone Research Institute, RRS, Bhuj at Krantiguru Shyamji Krishna Verma Kachchh University, Bhuj

National Symposium on Resource Utilization through Integrated Farming System and Biodiversity Conservation in Drylands during December 20-22, 2011

National Review Meeting on Cactus Pear during January 16-18, 2017

Other Important Meetings Organized

Date	Details
March 08-09, 2014	Annual Review Meeting of the externally-funded project on Understanding the adaptation mechanism of wild forage halophytes in the extreme saline-sodic kachchh plains for enhancing feed resources funded by National Fund for Basic, Strategic & Frontier Application Research in Agriculture (NFBSFARA), Indian Council of Agricultural Research, New Delhi
March 27, 2015	Annual Review Meeting of the externally-funded project on Understanding the adaptation mechanism of wild forage halophytes in the extreme saline-sodic kachchh plains for enhancing feed resources funded by National Fund for Basic, Strategic & Frontier Application Research in Agriculture (NFBSFARA), Indian Council of Agricultural Research, New Delhi
April 07, 2015	Agriculture Management Committee and Agriculture Governing Board meeting organized by ATMA & DDO, Bhuj
March 10, 2016	Annual Review Meeting of the externally-funded project on Understanding the adaptation mechanism of wild forage halophytes in the extreme saline-sodic kachchh plains for enhancing feed resources funded by National Fund for Basic, Strategic & Frontier Application Research in Agriculture (NFBSFARA), Indian Council of Agricultural Research, New Delhi

Jal Shakti Abhiyan

Two Farmers' Fairs were organized under Jal Shakti Abhiyan, as per Government of India directives, one at Kotda Chakar on September 03, 2019 and another at Sangamner (Bhachau) on October 02, 2019. About 1000 farmers from Sangamner, Sukhpar, Gunateepur, Kotda Chakar and other nearby villages participated in the programs along with officials from other state line departments and NGOs. Discussion on generating awareness about the present situation of water scarcity and measures for conservation of water in the country/world took place.

Fertilizer Application Awareness Program

A meeting was organized on creating awareness about balanced use of fertilizers in agriculture on October 22, 2019 in which around 100 farmers from nearby villages participated. Discussion on why use of fertilizer in a balanced way is important was held.

World Soil Health Day

World Soil Health Day was celebrated on December 05, 2019 at the station. A total of 24 participants from nearby villages attended the program. Importance of soil heath and ways in which it can be improved was discussed. The process of soil sample collection for soil testing was demonstrated to the farmers.

Farmers' Day and Constitution Day

Farmers' Day on December 23, 2019 and Constitution Day on December 25, 2019 were celebrated at the station. A total of 28 participants participated in the programs.

Capacity Building

Date	Name of training course, organizers and venue	Name of participant(s)
January 10-15, 2011	Training Program on Data Analysis Using SAS Software under Strengthening Statistical Computing for NARS organized by Department of Agriculture Economics & Management, Rajasthan College of Agriculture, MPUAT, Udaipur	Arvind Kumar
March 29, 2011	Training on Water Management organized by Central Ground Water Board, Western Region, Jaipur at ICAR-Central Arid Zone Research Institute, Jodhpur	Deepesh Machiwal
July 18-29, 2011	SAARC Training Program on Techniques of Water Conservation & Rainwater Harvesting for Drought Management at ICAR-Central Research Institute for Dryland Agriculture, Hyderabad	Deepesh Machiwal
August 29 - September 07, 2011	Short Course on Bioinformatics in Agriculture organized by ICAR-Indian Agricultural Statistics Research Institute, New Delhi	Arvind Kumar
August 01-07, 2012	Institutional Innovations in Agri-Extension for Inclusive Growth organized by NAARM, Hyderabad	Sushil Kumar
October 23- November 12, 2013	Advances in Experimental Designs for Development of Technologies in Agriculture organized by ICAR-Indian Agricultural Statistics Research Institute, New Delhi	Sushil Kumar
January 06-26, 2014	Winter School on Molecular Breeding Approaches for Genetic Enhancement of Millet Crops organized by ICAR-Directorate of Sorghum Research, Hyderabad	Arvind Kumar
March 24-28, 2014	National Training Course on Drought Mitigation and Management organized by ICAR-CAZRI and NIDM, Jodhpur	Sushil Kumar
November 11- December 01, 2014	Winter School on Diagnosis, Assessment and Management of Salt Affected Soils and Poor Quality Waters to Improve Productivity and Livelihood Security at ICAR-Central Soil Salinity Research Institute, Karnal, Haryana.	Shamsudheen Mangalassery
September 05-25, 2015	ICAR-sponsored Short Course on Novel Genomic Tools and Modern Breeding Approaches for Enhancing Productivity and Nutritional Quality of Pulse Crops organized by ICAR-IIPR, Kanpur	Rahul Dev
August 03-23, 2016	Summer School on Livelihood and Climate Change Mitigation and Adaptation through Agroforestry at ICAR-Central Arid Zone Research Institute, Jodhpur	M. Sureshkumar
September 07-27, 2016	Winter School on Designing and Analysis of Cropping Systems Experiments at ICAR-Indian Agricultural Statistics Research Institute, New Delhi	Gulshan Kumar Sharma
December 1-21, 2016	21-Days Winter School on Geospatial Technologies sponsored by DST, New Delhi organized at Chitkara University, Himachal Pradesh	Deepesh Machiwal
February 07-11, 2017	Tier II Training Program on Sustainable Development and Management of Ground Water Resources organized by Central Ground Water Board, West Central Region under the aegis of National Ground Water Training & Research Institute, Raipur held at Bhuj, Kachchh	Deepesh Machiwal Gulshan Kumar Sharma

Date	Name of training course, organizers and venue	Name of participant(s)
September 24-October 14, 2018	ICAR-sponsored 21 Days Winter School on Current and Emerging Trends for Conservation and Sustainable Utilization of Forest Genetic Resources organized by Navsari Agricultural University, Navsari, Gujarat	M. Sureshkumar
December 28-January 17, 2018	CAFT Training Program on Recent Developments in Statistical Modelling and Forecasting in Agriculture organized by ICAR-Indian Agricultural Statistics Research Institute, New Delhi	M. Sureshkumar
July 13-19, 2019	Cactus Pear Evaluation & Best-Agronomic Practices organized by ICARDA, Amman, Jordan	Rahul Dev
December 03-12, 2019	Short Course on Post-Harvest Management for Economic Security of Farmers in Arid Zone organized by ICAR-Central Arid Zone Research Institute, Jodhpur	Anandkumar Naorem
October 05-16, 2020	Training on Remote Sensing & GIS: Technologies & Applications organized by ICAR-National Bureau of Soil Survey & Land Use Planning, Regional Centre, Jorhat, Assam (virtual mode)	Anandkumar Naorem

Participation In Conference/Seminar/ Symposia/Workshop/Meeting

Date	Name of seminar/symposium, organizers and venue	Participants
February 28, 2011	National Workshop on Developing Water Use Efficiency organized by Central Ground Water Board, Western Region, Jaipur at ICAR-Central Arid Zone Research Institute, Jodhpur	Deepesh Machiwal
March 04-05, 2011	Symposium on Banni Grassland organized by Gujarat Institute of Desert Ecology (GUIDE), Bhuj, Kachchh	Devi Dayal Deepesh Machiwal Arvind Kumar
March 23-24, 2011	National Workshop on *Prosopis juliflora*: Past, Present and Future organized by ICAR-CAZRI, Jodhpur	Devi Dayal
June 20-24, 2011	National Workshop on Advance Soft Computing Techniques in Hydrology and its Applications organized by National Institute of Hydrology, Roorkee, Uttarakhand	Deepesh Machiwal
December 20-22, 2011	National Symposium on Resource Utilization through Integrated Farming System and Biodiversity Conservation in Drylands organized by AZRAI and ICAR-CAZRI, Jodhpur	Devi Dayal Deepesh Machiwal Arvind Kumar
December 01-02, 2012	Symposium on Managing Stress in Dry lands under Climate Change Scenarios organized by AZRAI and ICAR-Central Arid Zone Research Institute, Jodhpur	Devi Dayal Deepesh Machiwal Arvind Kumar Sushil Kumar
February 25-27, 2013	6th GEOSS Asia-Pacific Symposium on Accelerating Interlinkages in the Asia Pacific Region for Global Earth observations organized by Group on Earth Observation, ISRO and MEXT, Japan	Deepesh Machiwal
February 26-28, 2013	National Workshop on *Prosopis juliflora*: Retrospect and Prospects organized by CAZRI, Jodhpur at ICAR-CAZRI, RRS, Bhuj	Devi Dayal Sushil Kumar
March 04-07, 2013	NAIP-sponsored workshop on Scientific Report Writing and Presentation organized by NAARM, Hyderabad	Sushil Kumar
December 17-19, 2013	National Workshop on Revitalizing Rainfed Agriculture in Arid Regions - A Learning Program on Rainfed Farming Systems organized by National Institute of Agricultural Extension Management, Hyderabad	Deepesh Machiwal
February 15-16, 2014	National Conference on Biodiversity and Ecological Sustainability by the Academy of Plant Science India at SCS (J) College, Puri, Odisha	Devi Dayal
February 25-26, 2014	Regional Workshop on Water Resources Conservation: Village Ponds and Lakes organized by Centre for Science and Environment, New Delhi	Deepesh Machiwal
March 14-15, 2014	Workshop on Targeting Climate Resilient Agricultural Technologies in Arid Western India by National Initiative on Climate Resilient Agriculture (NICRA) at ICAR-Central Arid Zone Research Institute, Jodhpur	Sushil Kumar
March 21, 2014	National Workshop on *Cactus Pear* at ICAR-Central Arid Zone Research Institute, Jodhpur	Devi Dayal Arvind Kumar
January 16, 2015	One-day Workshop on Sustainable Development and Water Management organized by Irrigation Department, Zila Panchayat, Bhuj and Ministry of Water Resources, River Development and Ganga Rejuvanation, Government of India	Shamsudheen Mangalassery

Date	Name of seminar/symposium, organizers and venue	Participants
July 23-24, 2015	Enhancing Drinking Water Security through Participatory Good Water Management organized by WASMO, CGWB and ACT at Bhuj	Devi Dayal
September 24, 2015	Farmers' Fair organized by ICAR-Central Arid Zone Research Institute, Jodhpur	Devi Dayal
November 20-24, 2015	XXIII International Grassland Congress (IGC) 2015 organized by Range Management Society of India and ICAR-Indian Grassland and Fodder Research Institute, Vigyan Bhawan, New Delhi	Devi Dayal Shamsudheen Mangalassery
February 08-10, 2016	Workshop on Forward Thinking for Agricultural Development in Western India at SDAU, Palanpur	Devi Dayal
February 26, 2016	Workshop on Climate Change Mitigation and Adaptation in Hot Arid Region at RRS, ICAR-CAZRI, Bikaner	M. Sureshkumar
November 10-13, 2016	International Conference on Integrated Land Use Planning for Smart Agriculture - An Agenda for Sustainable Land Management (ICILUPSA-2016), organized by Indian Society of Soil Survey and Land Use Planning and ICAR-NBSSLUP, Nagpur	Shamsudheen Mangalassery
March 03-04, 2017	National Symposium on New Directions In Managing Forage Resources and Livestock Productivity in 21st Century: Challenges and Opportunities organized by Range Management Society of India and ICAR-Indian Grassland and Fodder Research Institute, Jhansi	Devi Dayal
January 16-18, 2017	National Review Meeting on Cactus organized by ICAR-Central Arid Zone Research Institute, RRS, Bhuj at Krantiguru Shyamji Krishna Verma Kachchh University, Bhuj, Gujarat	Devi Dayal Deepesh Machiwal Shamsudheen Mangalassery Rahul Dev M. Sureshkumar Gulshan Kumar Sharma
April 03-07, 2017	XIX Commonwealth Forestry Conference organized at Forest Research Institute, Dehradun	M. Sureshkumar
February 14-17, 2018	International Conference on Sustainability of Smallholder Agriculture in Developing Countries under Changing Climatic Scenario at C.S. Azad University of Agriculture & Technology, Kanpur Campus, Uttar Pradesh	M. Sureshkumar
November 17-18, 2018	International Conference on Impact of Climate Change & Abiotic Stresses on Agriculture & Management Strategies organized by Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh	Sushil Kumar
November 27-29, 2018	International Conference on Emerging Issues in Agricultural, Environmental & Applied Sciences for Sustainable Development organized by SHUATS, Allahabad, India.	Sushil Kumar
January 24, 2019	ICAR-NRM Divisional Meeting on Externally-Funded Projects, New Delhi	Devi Dayal
February 04-05, 2019	ICAR-Regional Committee Meeting, Anand, Gujarat	Devi Dayal
February 07-09, 2019	Golden Jubilee International Salinity Conference on Resilient Agriculture in Saline Environments under Changing Climate: Challenges & Opportunities organized by Indian Society of Soil Salinity and Water Quality, Karnal, Haryana.	Rahul Dev
February 11-14, 2019	13th International Conference on Development of Drylands: Converting Drylands from Grey to Green organized by ICAR-Central Arid Zone Research Institute, Jodhpur	Devi Dayal

Participation in Meetings with State Line Departments and other Agencies

Date	Department/agency	Subject	Place	Name of participants
April 08, 2016	Forest Department, Government of Gujarat	Discussion on grassland development in Banni area	Hodko, Banni, Bhuj	Devi Dayal
July 15, 2016	Gujarat Ecology Mission	Integrated Coastal Zone Management Project District level Dialogue	Bhuj	Deepesh Machiwal
October 18, 2016	Sardar-Krushinagar Dantiwada Agricultural University (SDAU), Gujarat	ZREAC Meeting	Dantiwada, Gujarat	Devi Dayal
July 25, 2018	Department of Agriculture, Government of Gujarat	Executive Committee Meeting of State Food Security Mission	Gandhinagar, Gujarat	Devi Dayal
July 18, 2019	Indian Council of Agricultural Research, New Delhi	ICAR Divisional Meeting on Foreign Aided Project	ICAR-Central Soil Salinity Research Institute, Karnal	Devi Dayal
November 21-22, 2019	National Dairy Development Board (NDDB), Anand	National Meet on Animal Nutrition	NDDB, Anand, Gujarat	Devi Dayal Anandkumar Naorem

Publications

Research Papers

Dayal, D., Mangalassery, S., Meena, S.L. and Ram, B. 2015. Productivity and profitability of legumes as influenced by integrated nutrient management with fruit crops under hot arid ecology. *Indian Journal of Agronomy* 60(2): 297-300.

Dev, R., Sharma, G.K., Singh, T., Dayal, D. and Sureshkumar, M. 2017. Distribution of *Grewia* species in Kachchh Gujarat, India: Taxonomy, traditional knowledge and economic potentialities. *International Journal of Pure & Applied Bioscience* 5(3): 567-574.

Dev, R., Sureshkumar, M., Dayal, D. and Venkatesan, K. 2017. Genetic diversity among wild *Grewia tenax* accessions collected from Kachchh region of Gujarat, India. *Indian Journal of Plant Genetic Resources* 30(3): 286-292.

Dev, R., Singh, J.P., Singh, T. and Dayal, D. 2018. Effect of shade levels on growth, and biomass production of cactus (*Opuntia ficus-india* (L.) Mill.). *International Journal of Current Microbiology and Applied Sciences* 7: 3145-3153.

Dev, R., Sureshkumar, M., Sharma, G.K., Singh, T. and Dayal, D. 2018. Effect of gibberellic acid (GA3) and oxalic acid on colour retention and storage quality of cold stored ber fruit cv. Gola. *Indian Journal of Horticulture* 75(1): 124-129.

Dev, R., Sureshkumar, M., Venkatesan, K., Singh, T. and Dayal, D. 2018. Morphological and pomological diversity among hairy-leaf cross berry (*Grewia villosa* wild) genotypes of arid Kachchh, Gujarat, India. *International Journal of Current Microbiology and Applied Sciences* 7(1): 1163-1172.

Kumar, A., Kumar, A., Lata, C., Kumar, S., Mangalassery, S., Singh J.P., Misra, A.K. and Dayal, D. 2018. Effect of salinity and alkalinity on response of halophytic grasses *Sporobolus marginatus* and *Urochondra setulosa*. *Indian Journal of Agricultural Sciences* 88(8): 1296-1304.

Kumar, S., Machiwal, D., Dayal, D. and Mishra, A.K. 2016. Enhanced quality fodder production through grass-legume intercropping under arid eco-system of Kachchh, Gujarat. *Legume Research* 40(5): 896-900.

Kumar, S., Machiwal, D. and Dayal, D. 2017. Spatial modeling of rainfall trends using satellite datasets and geographic information system. *Hydrological Sciences Journal* 62(10): 1636-1653.

Louhaichi, M., Kumar, K., Tiwari, S., Islam, M., Hassan, S., Yadav, O.P., Dayal, D., Moyo, H.P., Dev, R. and Sarker, A. 2018. Adoption and utilization of cactus pear in south asia-smallholder farmers' perceptions. *Sustainability 10*(10), 3625 DOI: 10.3390/su10103625.

Machiwal, D., Dayal, D. and Kumar, S. 2015. Assessment of reservoir sedimentation in arid region watershed of Gujarat. *Journal of Agricultural Engineering* 52(4): 40-49.

Machiwal, D., Kumar, S. and Dayal, D. 2016. Characterizing rainfall of hot arid region by using time series modeling and sustainability approaches: A case study from Gujarat, India. *Theoretical and Applied Climatology* 124: 593-607.

Machiwal, D., Dayal, D. and Kumar, S. 2017. Estimating water balance of small reservoirs in arid regions: A case study from Kachchh, India. *Agricultural Research* 6(1): 57-65.

Machiwal, D., Dayal, D. and Kumar, S. 2017. Long-term rainfall trends and change points in hot and cold arid regions of India. *Hydrological Sciences Journal* 62(7): 1050-1066.

Machiwal, D., Kumar, S., Dayal, D. and Mangalassery, S. 2017. Identifying abrupt changes and detecting gradual trends of annual rainfall in an Indian arid region under heightened rainfall rise regime. *International Journal of Climatology* 37(5): 2719-2733.

Machiwal, D., Cloutier, V., Güler, C. and Kazakis, N. 2018. A review of GIS-integrated statistical techniques for groundwater quality evaluation and protection. *Environmental Earth Sciences* 77:681, DOI: 10.1007/s12665-018-7872-x

Machiwal, D., Jha, M.K., Singh, V.P. and Mohan, C. 2018. Assessment and mapping of groundwater vulnerability to pollution: Current status and challenges. *Earth-Science Reviews* 185: 901-927.

Machiwal, D., Kumar, S. and Dayal, D. 2018. Evaluating cost-effectiveness of rainwater harvesting for irrigation in arid climate of Gujarat, India. *Water Conservation Science and Engineering* 3(4): 289-303.

Machiwal, D., Kumar, S., Sharma, G.K., Jat, S.R. and Dayal, D. 2018. Understanding a successful indigenous rainwater harvesting system in Banni area of Kachchh, Gujarat. *Indian Journal of Traditional Knowledge* 17(3): 559-568.

Machiwal, D., Gupta, A., Jha, M.K. and Kamble, T. 2019. Analysis of trend in temperature and rainfall time series of an Indian arid region: Comparative evaluation of salient techniques. *Theoretical and Applied Climatology* 136(1-2): 301-320.

Machiwal, D., Kumar, S., Meena, H.M., Santra, P., Singh, R.K. and Singh, D.V. 2019. Clustering of rainfall stations and distinguishing influential factors using PCA and HCA techniques over western dry region of India. *Meteorological Applications* 26(2): 300-311.

Machiwal, D., Jha, M.K. and Gupta, A. 2020. Development of a rainfall stability index using probabilistic indicators. *Ecological Indicators* 115, 106406, DOI: 10.1016/j.ecolind.2020. 106406.

Mangalassery, S., Dayal, D., Meena, S.L. and Ram, B. 2014. Carbon sequestration in agroforestry and pasture systems in arid northwestern India. *Current Science* 107(8): 1290-1293.

Mangalassery, S., Dayal, D., Ram, B. and Meena, S.L. 2014. Effect of tillage and soil amendments on soil quality and yield of clusterbean (*Cyamopsis tetragonoloba*) in shallow hardpan soils of arid Gujarat. *Indian Journal of Agricultural Sciences* 84(3): 428-431.

Mangalassery, S., Dayal, D., Kumar, A., Bhatt, K., Nakar, R., Kumar, A., Singh, J.P. and Misra, A.K. 2017. Pattern of salt accumulation and its impact on salinity tolerance in two halophyte grasses in extreme saline desert in India. *Indian Journal of Experimental Biology* 55(8): 542-548.

Mangalassery, S., Dayal, D., Kumar, A. and Dev, R. 2017. Evaluation of *cactus pear* (*Opuntia ficus-indica*) accessions for various growth characteristics under arid region of north Western India. *Range Management and Agroforestry* 38(2): 280-284.

Mangalassery, S., Dayal, D. and Jat, S.R. 2018. Potassium fractions under different land use systems in Kachchh region of Gujarat, India. *Journal of Environmental and Agricultural Systems* 1: 1-6.

Manjunatha, B.L., Mangalassery, S., Sureshkumar, M., Tewari, P., Dayal, D. and Yadav, O.P. 2019. Occupational structure and determinants of household income of pastoralists in Banni grasslands in Gujarat. *Indian Journal of Animal Sciences* 89(4): 453-458.

Manjunatha, B.L., Sureshkumar, M., Tewari, P., Dayal, D. and Yadav, O.P. 2019. Livestock population dynamics in Banni grasslands of Gujarat. *Indian Journal of Animal Sciences* 89 (3): 319-323.

Moharana, P.C., Santra, P., Singh, D.V., Kumar, S., Goyal, R.K., Machiwal, D. and Yadav, O.P. 2016. ICAR-Central Arid Zone Research Institute, Jodhpur: Erosion processes and desertification in the Thar Desert of India. *Proceedings of the Indian National Science Academy* 82(3): 1117-1140.

Purbey, S.K., Meena, S.L. and Dev, R. 2019. Influence of soil working techniques and planting methods on growth performance of fruit plants in Kachchh region of Gujarat, India. *International Journal of Current Microbiology and Applied Sciences* 8(1): 1874-1882.

Ram, B., Dayal, D., Meena, S.L., Shamsudheen, M, Kumar, A., Machiwal, D. and Vyas, S.C. 2013. Morphological variability and stability for seed and forage yield of marvel grass (*Dichanthium annulatum* (Forssk.) Stapf) under north western arid rangeland of Gujarat-India. *Indian Journal of Genetics and Plant Breeding* 73: 342-346.

Ram, B., Meena, S.L., Devi Dayal, Shamsudheen, M. 2013. Stability in performance of marvel grass genotypes (*Dichanthium annulatum*) under north western arid rangeland. *Range Management and Agroforestry* 34(2): 151-154.

Books

Machiwal, D. and Jha, M.K. 2012. *Hydrologic Time Series Analysis: Theory and Practice*. Capital Publishing Company, New Delhi, India and Springer, The Netherlands, 303 p.

Dayal, D., Machiwal, D., Mangalassery, S. and Tripathi, R.S. 2016. *Improving Productivity of Drylands by Sustainable Resource Utilization and Management*. New India Publishing Agency, New Delhi, India, 350 p.

Mangalassery, S., Dayal, D. and Machiwal, D. 2017. *Soil and Water Management Strategies for Drylands*. Kalyani Publishers, New Delhi, 358 p.

Chapter in Books

Chand, K., Kumar, S., Dayal, D., Jangid, B.L. and Mangalassery, S. 2016. Economics of arable crops production in arid Gujarat. In: *Improving Productivity of Drylands by Sustainable Resource Utilization and Management* (Eds. D. Dayal, D. Machiwal, S. Mangalassery and R.S. Tripathi), New India Publishing Agency, New Delhi, pp. 337-348.

Dayal, D., Mangalassery, S. and Kumar, A. 2015. Banni grasslands of Kachchh, Gujarat, India: Problems, present status and prospects. In: *Grassland: A Global Resource Perspective* (Eds. P.K. Ghosh, S.K. Mahanta, J.B. Singh and P.S. Pathak), Range Management Society of India, Jhansi, pp. 105-121.

Dayal, D., Kumar, A., Swami, M.L., Machiwal, D., Mangalassery, S., Vyas, S.C. and Kunpara, H. 2016. Management practices for improved forage production of butterfly pea (*Clitoria ternatea*). In: *Improving Productivity of Drylands by Sustainable Resource Utilization and Management* (Eds. D. Dayal, D. Machiwal, S. Mangalassery and R.S. Tripathi), New India Publishing Agency, New Delhi, pp. 215-224.

Dayal, D., Mangalassery, S. and Singh, T. 2017. Irrigation water management for field crops in dry areas. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 224-243.

Dev, R., Singh, T., Kumar, S., Sureshkumar, M. and Dayal, D. 2017. Water management for horticultural crops in dry areas. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 167-195.

Dev, R., Kumar, S., Dayal, D. and Mangalssery, S. 2018. Evaluation of cactus pear on farmer's fields for growth and survival under arid conditions of Kachchh, Gujarat. In: *Cactus Pear (Opuntia ficus-indica)* (Eds. S. Kumar, D. Dayal, S. Mangalssery, R. Dev and O.P. Yadav), Proceeding of the National Review Meeting. ICAR-Central Arid Zone Research, Institute, Jodhpur, 143 p. ISBN No. 978-93-5311-372-8.

Dev, R., Kannan, V., Kumar, M.S., Dayal, D. and Patel R. 2019. *Grewia* species: Diversity, distribution, traditional knowledge and utilization. In: *Wild Fruits: Composition, Nutritional Value and Products* (Eds. A. Mariod), Springer.

Jayaraman, S., Naorem, A., Lal, R., Dalal, R.C. and Patra, A.K. 2020. No-Till farming systems in South Asia. In: *No-till Farming Systems for Sustainable Agriculture: Challenges and Opportunities* (Eds. Y. Dang, R. Dalal R. and N. Menzies), Springer, https://doi.org/10.1007/978-3-030-46409-7_26.

Kumar, A., Dayal, D., Mangalassery, S., Machiwal, D. and Vyas, S.C. 2016. Agro-morphological evaluation of sesame (*Sesamum indicum* L.) cultivars under low input environment of arid ecosystem. In: *Improving Productivity of Drylands by Sustainable Resource Utilization and Management* (Eds. D. Dayal, D. Machiwal, S. Mangalassery and R.S. Tripathi), New India Publishing Agency, New Delhi, pp. 263-276.

Kumar, A., Dayal, D., Ram, B. and Mangalassery, S. 2016. Assessment of sesame (*Sesamum indicum* L.) cultivars under different rainfall regimes in arid Gujarat. In: *Improving Productivity of Drylands by Sustainable Resource Utilization and Management* (Eds. D. Dayal, D. Machiwal, S. Mangalassery and R.S. Tripathi), New India Publishing Agency, New Delhi, pp. 277-292.

Kumar, A., Mangalassery, S., Dayal, D., Kumar, S. and Ramniwas. 2017. Importance of Cacti (*Opuntia* sp.) and its role in dryland management. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 303-318.

Kumar, S., Goyal, R.K., Gaur, M. and Dayal, D. 2016. Land capability assessment using remote sensing and GIS techniques. In: *Remote Sensing for Natural Resources Management & Monitoring* (Eds. M.K. Gaur, C.B. Pandey and R.K. Goyal). Scientific Publishers, Jodhpur, pp. 105-124.

Kumar, S., Dayal, D., Machiwal, D., Kumar, S., Dev, R. and Sureshkumar, M. 2017. Agronomical measures for conservation of soil and water resources in drylands. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 126-137.

Kumar, S., Dev, R., Mangalassery, S. and Dayal, D. 2017. Characteristics of arid soils and some management alternatives. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 138-148.

Kumar, S., Machiwal, D., Tetarwal, A.S., Ramniwas and Dayal, D. 2017. Soil erosion and runoff control in farmlands of dry areas. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 86-99.

Machiwal, D. 2015. Application of AHP-MCDM technique in GIS-based groundwater potential zoning. In: *Implications of Climate Change on Pedagogical Issues of Water Resources Management* (Eds. R. Subbaiah and G.V. Prajapati). Centre of Excellence on Soil and Water Management, Junagadh Agricultural University, Junagadh, Gujarat, pp. 178-188.

Machiwal, D. 2015. Application of GIS-based geospatial analyses for developing spatial distribution map of groundwater levels. In: *Implications of Climate Change on Pedagogical Issues of Water Resources Management* (Eds. R. Subbaiah and G.V. Prajapati). Centre of Excellence on Soil and Water Management, Junagadh Agricultural University, Junagadh, Gujarat, pp. 189-197.

Machiwal, D. 2015. Groundwater balance modeling for estimating recharge using geographic information system. In: *Implications of Climate Change on Pedagogical Issues of Water Resources Management* (Eds. R. Subbaiah and G.V. Prajapati). Centre of Excellence on Soil and Water Management, Junagadh Agricultural University, Junagadh, Gujarat, pp. 168-177.

Machiwal, D., Dayal, D. and Kumar, S. 2016. Need of soil and water conservation measures in arid Kachchh district of Gujarat. In: *Improving Productivity of Drylands by Sustainable Resource Utilization and Management* (Eds. D. Dayal, D. Machiwal, S. Mangalassery and R.S. Tripathi), New India Publishing Agency, New Delhi, pp. 83-96.

Machiwal, D., Kumar, S., Shamsudheen, M. and Dayal, D. 2016. Impact of climate change on rainfall, runoff and soil erosion in Indian arid zone and its mitigation strategies. In: *Climate Change and Environment - Concepts and Strategies to Mitigate Impacts* (Eds. D. Sharma and K.C. Sharma), New India Publishing Agency, New Delhi, pp. 145-163.

Machiwal, D., Kumar, S. and Dayal, D. 2017. Application of modelling techniques for soil and water management in ungauged catchments of dry areas. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 58-85.

Machiwal, D., Kumar, S. and Dayal, D. 2017. Techniques for conserving and harvesting water in arid regions. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 100-116.

Mangalassery, S., Ram, B., Meena, S.L., Kumar A., and Dayal, D. 2016. Performance of selected crops and grasses under varying soil depths in the arid region of Gujarat. In: *Improving Productivity of Drylands by Sustainable Resource Utilization and Management* (Eds. D. Dayal, D. Machiwal, S. Mangalassery and R.S. Tripathi), New India Publishing Agency, New Delhi, pp. 97-104.

Mangalassery, S., Kumar, M., Dayal, D. and Kumar, S. 2017. Improving productivity of drylands through integrated soil fertility management. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 1-11.

Mangalassery, S., Kumar, M., Santra, P., Jat, S.R. and Dayal, D. 2017. Strategies for soil carbon sequestration for mitigation of climate change in dry areas. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 12-23.

Ram, B., Dayal, D., Mangalassery, S., Kumar, A., Meena, S.L. and Kumar, N. 2016. Morphological evaluation of sesame (*Sesamum indicum* L.). In: *Improving Productivity of Drylands by Sustainable Resource Utilization and Management* (Eds. D. Dayal, D. Machiwal, S. Mangalassery and R.S. Tripathi), New India Publishing Agency, New Delhi, pp. 253-262.

Sharma, G.K., Dayal, D., Machiwal, D., Dev, R., Singh, T. and Singhal, T. 2017. Bioremediation strategies for treatment of polluted soils and water resources in dryland areas. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 244-260.

Sureshkumar, M., Dayal, D., Dev, R., Singh, T., and Jat, S.R. 2017. Silvipasture for arid soil management. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 280-302.

Tetarwal, A.S., Jat, M.K., Ramniwas, Kumar, S. and Dayal, D. 2017. Important soil borne pests and their integrated management in arid ecosystem. In: *Soil and Water Management Strategies for Drylands* (Eds. S. Mangalassery, D. Dayal and D. Machiwal), Kalyani Publishers, New Delhi, pp. 280-302.

Chapters in Proceedings of Seminar/Symposia/ Conference

Dayal, D. and Mangalassery, S. 2014. Diversified farming system for enhanced economic and ecological sustainability in arid Kachchh. In: *Proceedings of the National Conference on Biodiversity and Ecological Sustainability*. February 15-16, 2014. The Academy of Plant Science India. S.C.S (J) College, Puri, Odisha. pp. 25-27.

Dayal, D. and Mangalassery, S. 2017. Banni grasslands of Kachchh- Issues and strategies for enhancing productivity. In: *Souvenir of National Symposium on New Directions in Managing Forage Resources and Livestock Productivity in 21st Century: Challenges and Opportunities*. March 3-4, 2017. Range Management Society of India and ICAR-Indian Grassland and Fodder Research Institute, Jhansi, UP. pp. 24-29.

Dayal, D., Mangalassery, S., Misra, A.K., Kumar, A. and Meghwal, P.R. 2018. Introduction and evaluation of Cactus pear (*Opuntia ficus-indica*) in Kachchh, Gujarat as an alternate fodder resource. In: *National Review Meeting on Cactus pear (Opuntia ficus-indica) in India* (Eds. S. Kumar *et al*. 2018). ICAR-Central Arid Zone Research Institute, Jodhpur. ISBN No. 978-93-5311-372-8. pp. 81-88.

Yadav, O.P., Sureshkumar, M. and Dayal, D. 2018. Cactus pear research in India: Retrospects and prospects. In: *National Review Meeting on Cactus pear (Opuntia ficus-indica) in India* (Eds. S. Kumar *et al*. 2018). ICAR-Central Arid Zone Research, Institute, Jodhpur. ISBN No. 978-93-5311-372-8. pp. 133-143.

Technical Bulletins/Extension Folders

Moharana, P.C., Singh, D.V. and Kumar, A. 2011. *Souvenir of National Symposium on Resource Utilization through Integrated Farming System and Biodiversity Conservation in Drylands*. ICAR-Central Arid Zone Research Institute, Jodhpur.

Training Manuals

Dayal, D., Mangalassery, S., Kumar, S. and Machiwal, D. 2014. *Training Manual on Soil Sampling, Investigation of Problematic Soils and Laboratory Analysis*. ICAR-Central Arid Zone Research Institue, Regional Research Station, Bhuj, 73p.

Popular Articles

Dayal, D., Dev, R., Sureshkumar, M. and Manjunatha, B.L. 2018. Managing Banni grassland: Issues and opportunities. *Indian Farming* 68(9): 112-114.

Dev, R., Dayal, D. and Singh, T. 2017. Mycorrhizal bio-fertilizer: An effective tool to manage abiotic stress in crop plants of arid and semi-arid regions. *Indian Farming* 67(6): 30-33.

Dev, R., Sharma, G.K., Dubey, R. and Dayal, D. 2017. Datepalm: Post harvest value addition for better income. *किसान ज्ञान* 1(8): 10-12.

Dev, R., Singh, T. and Dayal, D. 2017. रसायनों से पकाये गए फलो के दुष्प्रभाव. *फलफूल* 38(6): 16-18.

Dev, R., Dayal, D., Mangalassery, S. and Yadav, O.P. 2018. Thornless cactus: An unconventional, valuable fodder resource in arid region of India. *Indian Farming* 68(9): 101-103.

Dev, R., Dayal, D. and Singh, T. 2018. Mycorrhizal biofertilizer an effective tool to manage abiotic stress in crop plants of arid and semi-arid regions. *Indian Farming* 68(6): 7-8.

Dev, R., Vyas, M., Machiwal, D. and Dayal, D. 2018. खनिज पदार्थों से भरपूर है फालसा. *फलफूल* 39(3): 25-27.

Kumar, S. and Machiwal, D. 2017. Grass-legume intercropping helps in livestock development. *Indian Farming* 67(7): 17-18.

Kumar, S., Machiwal, D. and Dayal, D. 2015. भूमिगत जल का सतही भंडारण. *खेती* 67(3): 20-25.

Kumar, S., Machiwal, D., Tetarwal, A.S., Singh, T. and Dayal, D. 2016. गेबियन संरचना द्वारा खेत से जल अपवाह का प्रभावी निकास. *खेती* 68(11): 5-10.

Kumar, S., Machiwal, D. and Banjara T. 2019. शुष्क क्षेत्रों में ऊपयोगी है घास के साथ दलहन उगाना. *खेती* 71(11): 48-50.

Machiwal, D., Dayal, D., Kumar, A., Kumar S., and Swami, M.L. 2013. शुष्क क्षेत्र में वर्षा जल के संग्रहण से फसल उत्पादन. *खेती* 65(12): 30-32.

Machiwal, D., Kumar, S. and Dayal, D. 2015. अब ओस की बून्दों से पेयजल. *खेती* 67(8): 11-13.

Machiwal, D., Kumar, S. and Dayal, D. 2015. यूकेलिप्टस वृक्ष के जल संरक्षण से जुड़े तथ्यों का मूल्यांकन. *खेती* 67(3): 33-37.

Machiwal, D., Kumar, S. and Dayal, D. 2017. Rainwater unable to quench the thirst, now hopes from dew drops. *Indian Farming* 67(12): 29-33.

Machiwal, D., Kumar, S., Sharma, G.K. and Dayal, D. 2017. विरड़ा – कच्छ में वर्षाजल संग्रहण का पारंपरिक तरीका. *खेती* 70(4): 43-46.

Machiwal, D., Kumawat, S., Dev, R. and Teterwal, A.S. 2017. गमलों में सब्जी उत्पादन. *फलफूल* 38(6): 7-8.

Sharma, G.K., Dev, R. and Dayal, D. 2017. Microalgae: Potential source of third generation Biofuel. *Indian Farming* 67(11): 15-17.

Sharma, G.K., Shamsudheen, M., Machiwal, D. and Dayal, D. 2017. Salinity Impact and mitigation strategy in Kachchh (arid) region. *किसान ज्ञान* 1(8): 18-20.

Sharma, G.K., Dev, R., Dayal D. and Singh, T. 2018. Enhancing solubility of low grade phosphorus minerals for their utilization as plant nutrients. *Indian Farming* 68(7): 24-26.

Singh, T., Dev, R. and Dayal, D. 2017. ुष्क क्षेत्रों में केंचुआ खाद अपनाए, खेती को समृद्ध बनाए. *फलफूल* 38(3): 15-20.

Singh, T., Dev, R., Sharma, G.K. and Dayal, D. 2017. कुसुम – कच्छ में उभरती हुई तिलहनी फसल. *खेती* सितम्बर: 35-40.

Extension Folders

Dev, R., Dayal, D., Ramniwas and Kumar, S. 2015. कच्छ, गुजरात की संकटग्रस्त औषधीय पादप प्रजातियों के लिए प्रबंधन रणनीति. ICAR-CAZRI, Regional Research Station, Bhuj, Gujarat.

Mangalassery, S., Dayal, D., Patel, S. and Patel, V. 2015. Cactus as fodder resource for arid Gujarat. ICAR-CAZRI, Regional Research Station, Bhuj, Gujarat, 6p.

Sureshkumar, M., Dayal, D., Dev, R. and Vaishnav, M. 2018. બબબબબબબબબબબબબબબબ બબબબ(Forage legumes for Banni grassland). In Gujarati, EF-1/18.

Sureshkumar, M., Dayal, D., Dev, R. and Vaishnav, M. 2018. બબબબબબબબબબબબબબબ બબબબબ (Grasses of Banni grassland). In Gujarati, EF-2/18.

Sureshkumar, M., Dayal, D., Dev, R. and Vaishnav, M. 2018. બબબબ બબબબબબ બબબબ બ બબબ બબબબ (Multipurpose trees suitable for Banni grassland). In Gujarati, EF-3/18.

Sureshkumar, M., Dayal, D., Dev, R. and Vaishnav, M. 2018. બબબબબ બબબબબબબબબબબબ (Establishment and restoration of Grassland). In Gujarati, EF-4/18.

Proccedings of Seminar/Conference

Kumar, S., Dayal, D., Mangalassery, S., Dev, R. and Yadav, O.P. 2018. Proceeding of National Review Meeting on Cactus pear (*Opuntia ficus-indica*) in India. ICAR-Central Arid Zone Research, Institute, Jodhpur, 143p. ISBN No. 978-93-5311-372-8.

Awards and Recognitions

The scientific and administrative staffs of the station have been awarded with several distinguished awards from academies, institutes, and universities during the period of 2011 to 2020, which are enlisted below.

- Dr. Deepesh Machiwal was conferred with "IEI Young Engineer Award" by The Institutions of Engineers (IEI) (India) in 25th National Convention of Agricultural Engineers held during January 19-20, 2012 at Kolkata, West Bengal.
- Dr. Deepesh Machiwal was felicitated with "Appreciation Award" by The Institutions of Engineers (India), Udaipur on Engineers' Day on September 15, 2012.
- Dr. Deepesh Machiwal was conferred "Distinguished Service Award" for the Year 2012-2013 by Indian Society of Agricultural Engineers (ISAE), New Delhi in 47th Annual Convention of ISAE during January 28-30, 2013 held at Hyderabad, Andhra Pradesh.
- Dr. Devi Dayal was awarded with "Gold Medal and APSI Distinguished Plant Scientist Award-2013" by the Academy of Plant Sciences, India at 23rd APSI scientists meet, Puri, Odisha during February 15-16, 2014.
- Dr. Deepesh Machiwal was conferred with "Outstanding Book Award (2013)" by the Indian Society of Agricultural Engineering (ISAE), New Delhi in 48th Annual Convention of ISAE held during February 21-23, 2014 at MPUAT, Udaipur for the book entitled, 'Hydrologic Time Series Analysis: Theory and Practice' published by Springer.
- Dr. Shamsudheen Mangalassery was selected as a Member of the International Soil Tillage Research Organization for contribution in tillage research.
- Dr. Devi Dayal was awarded Fellow of the Indian Society of Oilseed Research, 2015 by the Indian Society of Oilseed Research, Hyderabad, Andhra Pradesh.
- Dr. Deepesh Machiwal was awarded for "*Outstanding Contribution in Reviewing*" by Agricultural Water Management Journal, Elsevier, The Netherlands in May 2015.
- Dr. Deepesh Machiwal recieved "*Achiever Award - 2015*" from the Society for Advancement of Human and Nature (SADHNA), Himachal Pradesh.
- Dr. Deepesh Machiwal recieved "*Appreciation Award*" from The Institutions of Engineers (India), Udaipur on Engineers' Day (September 15, 2015).
- Dr. Deepesh Machiwal was conferred with Award of "*Outstanding Contribution in Reviewing*" by the Editors of Journal of Hydrology, Elsevier, The Netherlands in August 2017.
- Dr. Deepesh Machiwal was conferred with "*Certificate of Reviewing*" by the Editors of Journal of Hydrology, Elsevier, The Netherlands in August 2017.
- Dr. Rahul Dev received "Young Scientist Award" for outstanding contribution in the field of Fruit Science in International Conference on Agricultural and Applied Sciences for Promoting Food Security held during May 13-15, 2017 at Battishputli, Kathmandu, Nepal.
- Dr. Rahul Dev received "Young Scientist Award" in National Conference on Doubling Farmers Income for Sustainable and Harmonious Agriculture (DISHA-2017) held during September 09-10, 2017 at Sri Venkateshwara Veterinary University, Tirupati, Andhra Pradesh.

- Dr. Rahul Dev received "Outstanding Ph.D. Thesis Award" for outstanding contribution in the field of horticulture and plant genetic resources in National Conference on Livelihood and Food Security (LFS-2018) held during January 27-28, 2018 at Bihar Veterinary College, Patna, Bihar.
- Dr. Rahul Dev received "Best Ph.D. Thesis Award" for outstanding contribution in the field of agriculture and horticulture in International Seminar on Agriculture and Food for Inclusive Growth and Development held during January 14-15, 2017 at NBRI, Lucknow, Uttar Pradesh.
- Dr. Deepesh Machiwal was conferred with "Commendation Medal Award" by the Indian Society of Agricultural Engineers (ISAE), New Delhi on the occasion of 53rd Annual Convention of ISAE held at Banaras Hindu University, Varanasi.
- Dr. Deepesh Machiwal was conferred with "Best Paper Award" by the ICAR-Central Arid Zone Research Institute (CAZRI), Jodhpur on the occasion of 60th Institute Foundation Day on October 01, 2018.
- Dr. Deepesh Machiwal was selected as "Associate Editor" of *Journal of Agricultural Engineering* published by the Indian Society of Agricultural Engineering (ISAE), New Delhi in October 2018.

Distinguished Visitors

Date	Visitors
August 15, 2011	Dr. Mounir Louhaichi, Deputy General Coordinator of CACTUSNET project of FAO-ICARDA
December 20, 2011	Dr. A.K. Singh, Deputy Director General (Natural Resources Management), ICAR, New Delhi Dr. K.P.R. Vittal, Director, NIASM, Baramati Dr. Ashutosh Sarker, Regional Coordinator for South Asia & China Regional Program, ICARDA, New Delhi Dr. A. Bandyopadhyay, National Coordinator (NFBSFARA), ICAR, New Delhi
February 12-13, 2012	Dr. Ajit Verma, DG, Amity University, Jaipur
September 25, 2012	Sh. N.K. Joshi, General Manager (P), Gujarat Mineral Development Corporation, Gujarat
January 17-18, 2013	Dr. K.D. Kokate, Deputy Director General (Agricultural Extension), ICAR, New Delhi
December 13, 2013	Dr. R.R. Hanchinal, Chairperson, Protection of Plant Varieties & Farmers' Rights (PPV&FR) Authority, Ministry of Agriculture, Govt. of India, New Delhi
March 08-09, 2013	Dr. S.B.S. Tikka, Former Director of Research, Sardarkrushinagar Dantiwada Agricultural University, Gujarat
October 06, 2014	Dr. Ashok Ambalal Patel, Vice Chancellor, Sardarkrushinagar Dantiwada Agricultural University, Dantiwada Dr. R.R. Shah, Director of Research, Sardarkrushinagar Dantiwada Agricultural University, Sardar Krushi Nagar, Dantiwada
December 22, 2014	Dr. Panjab Singh, Former Secretary, DARE and DG, ICAR Dr. P.K. Ghosh, Director, ICAR-IGFRI, Jhansi Dr. C.L. Acharya, Ex-Director, ICAR-Indian Institute of Soil Science, Bhopal Dr. P.S. Pathak, Ex-ADG, ICAR, New Delhi Dr. A.K. Roy, Project Coordinator- Forage crops, ICAR-IGFRI, Jhansi
February 24, 2015	Dr. B.S. Patel, Vice Chancellor, KSKV Kachchh University, Bhuj
October 09, 2015	Dr. Mounir Louhaichi, Deputy General Coordinator of CACTUSNET project of FAO-ICARDA

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