Vision 2050

Central Research Institute for Dryland Agriculture

Indian Council of Agricultural Research

भाकृअनुप
ICAR

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

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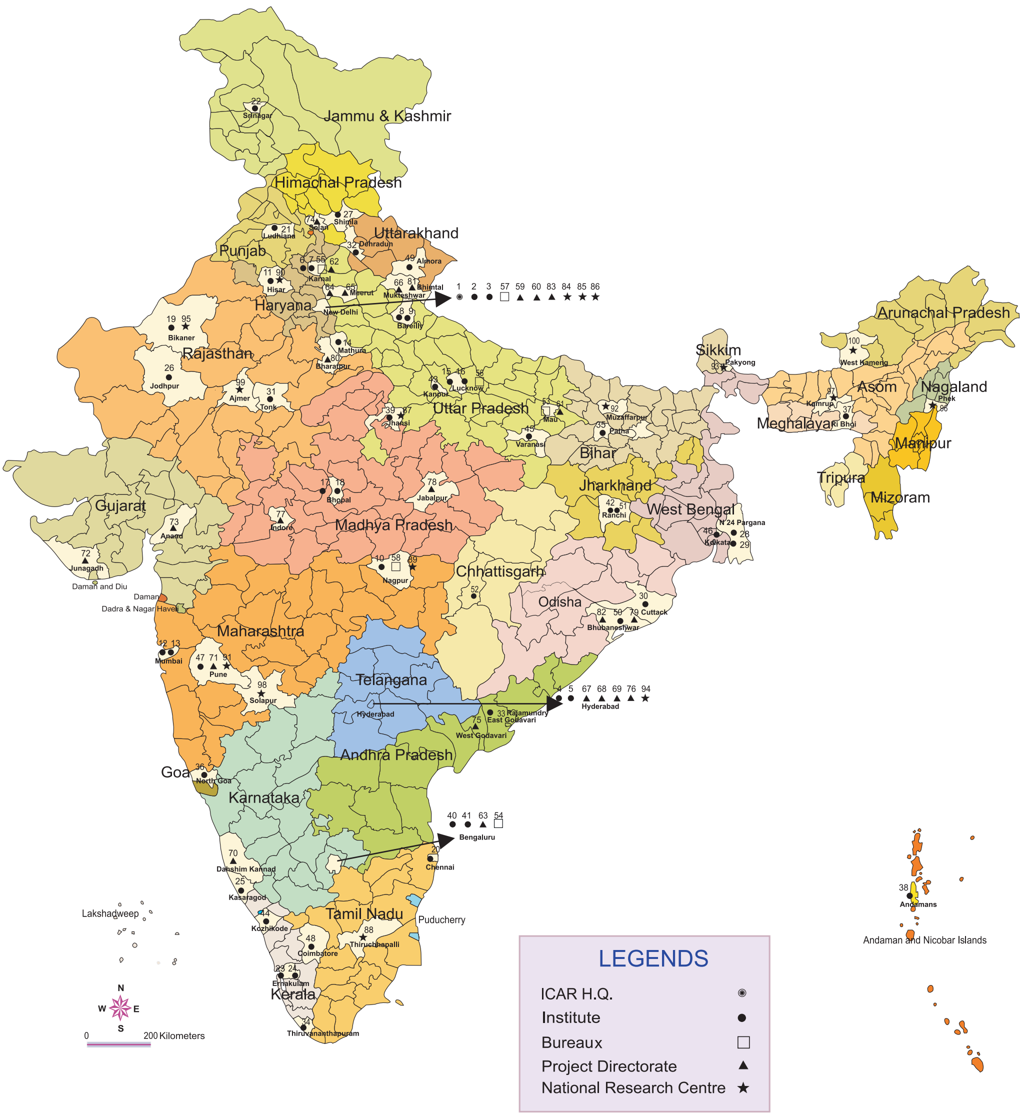

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Vision 2050

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संदेश

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

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

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

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

राधा मोहन सिंह

(राधा मोहन सिंह)

केन्द्रीय कृषि मंत्री, भारत सरकार

Foreword

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

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

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

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

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

(S. AYYAPPAN)
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Preface

Rainfed agriculture production systems in the country are diverse and heterogeneous. This sector currently produces 40% of the food grains and supports two-thirds of the livestock population. Nearly 40% of the population depends on rainfed agriculture and its performance is critical to enhance production and to achieve and sustain high agricultural growth in years to come. Despite increase in average productivity levels from 0.6 tonnes in the eighties to 1.2 tonnes at present, large yield gaps exist in several crops and regions between research stations and farmer's fields. This is a matter of concern, but therein also lies an opportunity. In order to achieve food and nutritional security and inclusive growth, considering the trend of diversification of the food requirements, the key is to maintain a steady growth in important rainfed crops. This vision document outlines the strategies that CRIDA seeks to implement to capitalize on this opportunity and enhance productivity in rainfed areas thus laying the path for the second green revolution.

The Central Research Institute for Dryland Agriculture (CRIDA) established in 1985 has played pioneering role in developing and disseminating improved rainfed farming technologies in different agro-ecological regions of the country. Over the last 30 years CRIDA and its network of research stations have developed and disseminated large number of technologies in rainwater management, watershed development, soil health management, cropping systems, farm machinery and diversified land use systems. Despite the good progress made so far, the adoption and diffusion of key rainfed technologies is still low, resulting in continuedyield gaps. In the coming years, utmost priority will be given to realizing the potential of existing technology by addressing the lacunae in current technology transfer models and deploying cutting edge information and communication technology to reach the farmers in the farthest and most inaccessible areas. Increasing climatic variability and climate change pose new challenges to Indian agriculture in terms of increased frequency of droughts, floods, cyclones, extreme temperatures, etc. The institute which is currently implementing the ICAR flagship programme, National Initiative on Climate Resilient Agriculture (NICRA), is playing an important role at national level in evolving adaptation and mitigation strategies in agriculture and allied sectors and also taking up their demonstration in more than 130 villages representing key climate vulnerabilities. Efforts are being made for scaling up these technologies through the National Mission for Sustainable Agriculture (NMSA). CRIDA has developed 580 district agriculture contingency plans involving all agricultural universities, several ICAR universities, Krishi Vigyan Kendra's (KVK's) and other stakeholders related to all the sectors of Agriculture. Near real time implementation of contingency plans is a daunting but important task to be achieved in the coming years through central and state government action plans.

Extreme climatic events such as drought and floods occurring in the same crop growing season can seriously undermine our efforts to enhance production using current technology. Emphasis is required on developing technologies such as multiple abiotic stress tolerant cultivars that can deal with climatic extremes. Water harvesting and recycling are critical for enhancing the productivity in rainfed agriculture. Focus will be made on the development of location specific technologies consisting of *in-situ* as well as *ex-situ* methods of conservationfor meeting the critical irrigation requirements. Apart from enhancing the availability of water, all out efforts are needed to maximize returns from every drop of harvested water. Our objective is to package the entire technology and link with the developmental programs for large scale adoption and impact.

Deteriorating soil health in rainfed agro ecosystems with depletion of soil organic matter and emerging multi nutrient deficiencies is another challenge. Location specific Integrated Nutrient Management (INM) technologies with locally available organic resources and crop residue recycling are important options. Input use in rainfed areas is presently low and will remain so in the foreseeable future. Productivity enhancement is impossible unless the efficiency of inputs is maximized. Precision farming approaches that involve more software than hardware and are customized to small and marginal farmers will be formulated to ensure site specific application of inputs for realizing more output from less input. Nanotechnology will be harnessed to further enhance input use efficiency through targeted smart delivery nano-products.

There exists a vast scope for accelerating agricultural growth in rainfed areas through diversification into high-value crops, horticulture, and livestock-based enterprises with available water. Livestock based systems are important in semi arid regions and play a crucial role in ensuring livelihood security in less-developed and tribal areas of the country. Efforts will be made to develop farm pond based resilient and profitable integrated farming system models and alternate land use systems throughon-station and on-farm research in different regions of the country.

The Vision 2050 of CRIDA has been developed after several rounds of discussions with scientists, experts and stakeholders. It outlines the future scenario, new and emerging challenges, the strength of the existing network and strategies to meet short- and long-term goals. The strategies for achieving the expected outcome are defined considering the multidisciplinary scientific team of the institute, its experience in working with a consortium approach and the lessons learnt from large number of multi-institutional action research projects implemented in recent years with a good balance between strategic research, technology development and upscaling through national programmes. The document also captures the opportunities of using new science tools and approaches in addressing problems hither to unresolved.

I take this opportunity to acknowledge the guidance received from Dr. S. Ayyappan, Director General, ICAR, Dr. A.K. Sikka, Deputy Director General (NRM) in the preparation of this document. I am also thankful to Dr. Mohan Kumar, ADG (Agronomy, Agroforestry and Climate Change) for constructive suggestions. I thank the Project Coordinators, Heads of Divisions and all the Scientists of CRIDA for providing valuable inputs for the document.

Director
CRIDA

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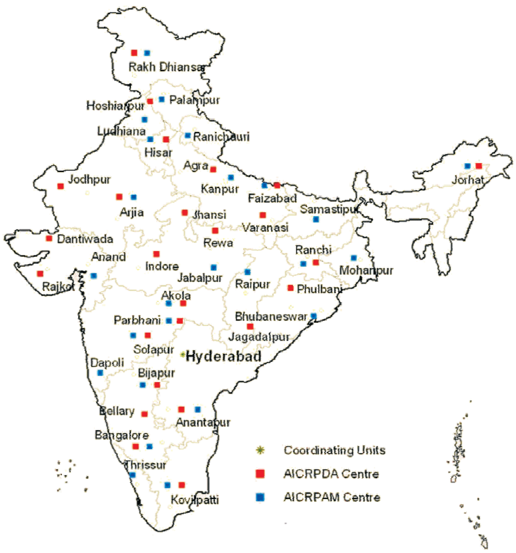
Context

NEARLY 40% of the net sown area in India will remain rainfed even after realizing the full irrigation potential. About 40% of the nation's food grains are produced in rainfed areas which also support two-thirds of the livestock population. Rainfed agriculture production systems in the country are characterized by diversity and heterogeneity. Although the average per hectare productivity levels have increased from 0.6 tonnes in the eighties to 1.2 tonnes at present, large gaps still remain in several crops and regions between yields obtained at research stations and in farmers' fields. This is both a concern as well as an opportunity. With the productivity of irrigated crops reaching a plateau due to declining factor productivity, rainfed agriculture still offers scope for enhancing productivity by bridging the yield gaps with the currently available technologies and also to raise the yield potential in high rainfall zones through development of improved technologies.

From the socio-economic perspective, farmers in rainfed regions face multiple risks of weather, credit and markets and therefore the need for improving productivity and income is more imperative in rainfed agriculture than irrigated farming. This is key to achieving equity and inclusive growth which are the main goals of XII Five Year Plan. While past research has certainly resulted in improved production, particularly, in coarse cereals and oilseeds, besides contributing to natural resources conservation, there are still many challenges. The changing socio-economic dynamics and food habits and challenges like land degradation and climate change necessitate greater attention and increased investments in dryland agriculture. It is in this context that CRIDA needs to envision the future scenario, identify the challenges and draw up suitable R&D strategies.

Historical

Earliest attempts to improve rainfed agriculture began in the erstwhile Bombay State. During 1933-35, the then Imperial (now Indian) Council of Agricultural Research (ICAR) initiated a broad-based dry farming research project at Solapur, Bijapur, Hagari, Raichur and Rohtak to formulate appropriate strategies. After independence, renewed efforts were made to improve stability and productivity of rainfed agriculture since 1950s through developing appropriate soil and water conservation practices. ICAR gave a new impetus by launching the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in 1970, based at Hyderabad with 23 cooperating centres spread across the country, ushering in an era of location specific adaptive research.



CRIDA and its Research Network

Strategic research

Realizing that the enormity and complexity of this sector requires basic and strategic research inputs, the Central Research Institute for Dryland Agriculture (CRIDA) was established at Hyderabad, on April 12, 1985 with the mandate of providing leadership in basic and strategic research in dryland agriculture and to address the location specific problems in association with AICRPDA centres. The importance of weather and the science of Agrometeorology in agriculture were realized around this time and the National Commission on Agriculture also recommended to strengthen research in Agrometeorology. The All India Coordinated Research Project on Agrometeorology (AICRPAM) was launched in 1983, also at CRIDA, Hyderabad, with 10 cooperating centres under different SAUs. Both AICRPDA and AICRPAM presently have 25 centres each.

While CRIDA undertakes lead research in dryland agriculture, solutions to location specific problems are generated through AICRPDA network. Further support to dryland agriculture research comes from understanding and defining crop growth related weather parameters - a core activity of AICRPAM. CRIDA also undertakes several outreach programmes involving non-governmental organizations through farmers' participatory action research with a livelihoods perspective.

Evolution of the research program

In the early seventies, when the dryland agriculture research program was started, it was mostly adaptive research carried out in different agro-ecological regions to come out with simple and do-able technologies which can improve the yields on farmers' fields with little or no inputs. During this period, simple agronomic practices, most suitable crops varieties and cropping systems, planting geometry, fertilizer management and weed control methods were developed which became the first set of improved practices for dryland agriculture in the country which were adopted by all the Agricultural Universities and became part of the package of practices of the State Governments. During the eighties, farm mechanization, agroforestry and operational research for technology transfer received more emphasis. With the establishment of CRIDA, basic and strategic research on dryland agriculture was initiated with emphasis on stress physiology, moisture and nutrient interactions, climatic water balance, crop weather relationships and agrometeorology. During the nineties, CRIDA built the entire research program on the outcome of the model watershed program and strengthened its outreach by working with several non-government organizations in a farmer participatory action research mode. CRIDA played a major role in coordinating the agro-ecosystem based research under the National Agricultural Technology Project (NATP), wherein extensive on-farm participatory research was taken up in more than 200 rainfed districts in five production systems, viz., rainfed rice, nutritious cereals, oilseeds, pulses and cotton. CRIDA-AICRPDA together developed 145 location specific technologies and the recommendations became part of the package of practices of the State Governments. Continuing the focus on participatory action research, CRIDA implemented the National Agricultural Innovation Project (NAIP), in which the research focus shifted from production enhancement to income and livelihood security resulting in several replicable models in the states of Telangana and Andhra Pradesh.

Significant achievements

The following are the key achievements of the Institute which contributed to natural resource conservation and improved productivity of major rainfed crops across the country.

- Agroclimatic characterization and delineation of areas suitable for different crops/cropping systems in rainfed regions, and assessment of drought probabilities
- Preparation of district level contingency plans for more than 580 districts in the country to help farmers to cope with monsoon aberrations
- District level climate vulnerability atlas was prepared

- Providing value added agrometeorological advisory services during crop season through networking with agricultural universities
- Development of location specific *in situ* moisture conservation practices for diverse soil and climatic conditions
- Mapping areas with potential for rainwater harvesting in the country and standardization of farm pond technology
- Strategies for agricultural drought management in dryland areas, contingency planning and required mid-season interventions
- Soil fertility management through INM, residue recycling and conservation agriculture practices
- Development, testing and commercialization of implements for timely agricultural operations such as planters, interculture implements, herbicide applicators, low-lift portable pump sets for lifting water from farm ponds, etc.
- Release of two improved dual purpose horse gram varieties (CRIDA 18R and CRHG 4) for cultivation in peninsular India
- Identification and popularization of K-636 variety of *Leucaena* for industrial biomass production
- Identification of micro organisms and development of commercial products for zinc solubilization and enhancing heat and drought tolerance in rainfed crops
- Development of weather-based pest and disease forewarning systems for major crops
- Development of alternate land use systems involving agri-silvi, silvi-pastoral, agri-horti and horti-pastural systems with focus on marginal lands
- Scalable models for enhancing livelihood security in rural areas through convergence of schemes at village level

In addition to enhancement of production, CRIDA's work on drought management and watershed development helped the country in formulating and implementing several national level programs like DPAP, NWDPRA and IWMP. The Institute has been actively contributing to the policies and technical backstopping to these major developmental schemes and large scale national programs like NMSA, MGNREGA and RKVY. Recently, the Institute has completed preparation of district wise contingency plans for more than 580 districts in the country for dealing with aberrant monsoon and its impact on agriculture.

Linkages for greater impact

The 6th QRT of CRIDA and AICRPs which comprehensively reviewed the basic and applied research programmes under the Institute, suggested increased linkages not only between the two AICRPs but also with institutions and AICRPs in other divisions and emphasized on outreach programs with field orientation. Accordingly, the Institute is planning to expand its functional network even outside the NARS system. All centres of AICRPDA have organized regional workshops involving KVKs and ATMAs in their domains. This is to facilitate speedy technology transfer in a decentralized manner. It is planned to formulate a structured and time bound plan in this regard. CRIDA is also envisaging linkages with international organizations like IWMI, ICRISAT and ICARDA in developing collaborative research programs particularly in climate change and dryland farming. The Institute is taking up pilot projects involving state departments of agriculture and rural development on quantifying environmental services of NRM based development programs and participates in National Mission on Sustainable Agriculture (NMSA) to carry out pilot testing of the district level contingency plans in selected states.

Addressing new challenges

Building on the early work done under the National Project on Climate Change (NPCC), ICAR launched the National Initiative on Climate Resilient Agriculture (NICRA) in 2011 which is being coordinated by CRIDA. The project has a strategic research component to address long term climate change, participatory technology demonstration in farmers' fields in the most vulnerable districts to cope with the current climate variability and capacity building of stakeholders at different levels. In the XI Five Year Plan, the project made significant progress in establishing state of the art infrastructure for controlled studies on elevated temperature and CO_2, high throughput phenotyping of crop germplasm and nationwide monitoring of greenhouse gas emissions. Proven climate resilient technologies are being demonstrated to increase the adaptive capacity of farmers.

Contributing to national goals

The major goal of public sector research being helping the poor and disadvantaged, CRIDA needs to play continued role in addressing the problems of dryland agriculture, the mainstay of small and marginal farmers. Although private sector is emerging as a major player in R&D, so far their attention has been only on hybrid seeds and very few self-pollinated rainfed crops are part of their business model. CRIDA has to lead the NARS in evolving sustainable village level seed production models for such crops and also continue its focus on natural resource management and climate change adaptation which are largely the domain of the public sector. To achieve the goals of equity, sustainability and environmental stability which the country is aiming, improving rainfed agriculture is critical for which CRIDA is committed. The institute therefore has a key role in the larger national development goals of the country to catalyze the second green revolution through equitable development of disadvantaged regions and people.

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Challenges

THE major challenge of rainfed agriculture in the decades to come will be sustaining the livelihoods of small and marginal farmers who will still depend on agriculture despite increased climate variability and shrinking land holdings. Failure to address this challenge will lead to substantial shift of rural youth to service sector resulting in huge manpower shortage in farming. The growing preference for commercial crops even in less endowed areas will put further pressure on land and water resources and enhances the risk. The challenge therefore lies in balancing the land use and cropping pattern as per the resource capability and shifting markets. Some of the challenges like retaining area under the nutritious cereals can be converted into opportunities with by spreading awareness on the health benefits of these crops. The key challenges are described below.

Managing risks

Rainfed agriculture is synonymous with risk due to erratic monsoon. Low and variable productivity levels are an impediment to investment by resource-poor farmers. Climatic risks like droughts and floods and edaphic constraints like poor water and nutrient retention capacity and lowsoil organic matter (SOM) make rainfed agriculture highly vulnerable, requiring a different outlook and strategy. There is ample evidence on the benefits of improving SOM through biomass recycling and integrated nutrient management on stability and yields of rainfed crops. Similarly, the economic benefits from rain water harvesting at farm level have been well documented. Translating these evidences into wider adoption constitutes the short and medium term challenge.

Risk is also to be addressed in terms of building resilience of crops, soils and farmers. Appropriate technologies including crop diversification; developing crop genotypes with high and stable yields coupled with abiotic and biotic stress tolerance; location specific soil and water conservation measures, alternate land use systems and integrated farming systems have to be evolved and promoted through a participatory approach. Increasing resource use efficiency for enhancing system productivity is pivotal for maintaining the productivity levels in rainfed agriculture. For sustainable livelihoods, current extension system promoting commodity based technologies needs to be reoriented towards harnessing incremental yield benefits through adoption of technologies that efficiently use natural resources and enhance the system productivity. This needs a whole breed of new extension personnel who will adopt a participatory approach.

Bridging yield gaps

The gap in yields between research stations and farmers' fields are still wide but are expected to narrow down in the future. However in several disadvantaged areas, the yield gaps will continue to remain large even in 2050, both due to non-adoption of technologies and non-availability of tailor-made package of practices. While evolving strategies for bridging yield gaps, due attention must be given to regional imbalances in terms of natural resources and technology intake capacity of farmers. For yield maximization, selecting genotypes with wide adaptability and resilience to climate variability remains a challenge. Developing crop simulation models and region specific decision support systems is another area that needs urgent attention.

The projected area, production and yield of cereals under various production systems in India for 2030 and 2050 are shown in Table 1. These projections assume little impact of technology in rainfed production systems. While irrigated systems can contribute an additional yield of 15%, the rainfed systems could remain the same. Thus, there would be need for a strategic mix of better technology adoption, institutional innovations and incentives system to enhance productivity of rainfed cereals.

Eroding demand for some of the rainfed commodities is another challenge while other crops are enjoying favourable market demand.

Table 1. Projected area, yield and production of cereals under different production systems of India

Cereals	2030	2050
Rainfed area (m ha)	40	36
Rainfed yield (t/ha)	1.8	2.0
Rainfed production (mt)	73	72
Irrigated area (m ha)	57	62
Irrigated yield (t/ha)	4.3	4.6
Irrigated production (mt)	248	285
Total area (mha)	97	98
Total yield (t/ha)	3.3	3.7
Total production (mt)	321	357

Source: Observations, projections and impacts – India 2011 UK Met office report

Therefore, technologies are to be developed for those crops which have expanding markets but are difficult to be grown in rainfed conditions. Wherever appropriate, steps must be taken to contribute to formulation of policies for promoting crops that are not so resource-demanding but at the same juncture have better food, nutrition and fodder value.

Concerns on nutritional security

Cereal yields in rainfed areas in India are projected to rise from 1.4 t per ha in 1999-01 to 2.0 t in 2050. Total cereal demand is projected to grow by 1048 mt, out of which 45% is expected from maize; 26% from wheat; 8% from rice; and the rest from minor millets and other coarse grains. Rapid growth in meat and milk production in most of the developing world will put pressure on maize and other coarse grains for use as feed. Globally, 41% of total cereal demand i.e. about 430 mt would be required for feed purpose by 2050, out of which slightly more than 60% would be for maize. About 16% of cereal demand is expected to be for biofuels.

The high levels of malnutrition, especially among poor, needs immediate attention as this affects their contribution to the national GDP. Output of cereals has increased at a much faster rate than population during the post green revolution period till mid-1990s, peaking to 501 g/day in 1995-96 and then declining slightly. However, output of pulses has remained almost stagnant for a long time resulting in protein malnutrition. The estimated undernourished population would be around 70 m which would account for 5% of the population assuming that dietary energy supply would rise from current 2500 kcal/person/day to 3020 kcal/person/day by 2050. Biofortification of rainfed crops, particularly millets would be the future challenge as most of the tribal people and farm labourers in dryland areas suffer from protein and micronutrient malnutrition.

Environmental footprints of changing demand profile

With rising incomes, the demand for high energy food (milk, meat, eggs and oils) will increase. For instance, milk and meat demands in India by 2050 are estimated to be around 110 and 18.3 mt respectively.Such production levels could be attained by intensive animal rearing systems like semi- and stall-feeding; placing more demand for fodder, feed and water; and breed improvement. However, meat and milk production systems are considered less energy-efficient (in conversion of plant proteins into animal proteins) and contribute to emission of green house gases. The problem is complex and a simple solution like cutting down animal production in developing countries will not work as small-scale animal farming contributes significantly to livelihoods of the poor.

The projected domestic demand for different crop groups shows that rice and wheat may be surplus whereas other cereals will be in acute shortage (Fig. 1). Out of 59mt shortfall, most of the produce will constitute maize which would go for animal/poultry feed. Also, the deficit would be primarily for oilseeds, fruits, vegetables and pulses. Hence, the challenge would be to enhance productivity levels of these crops by promoting breeding programs and dryland horticulture. Further, as rice and wheat are going to be surplus, we need to follow a two-pronged strategy i.e. to increase their productivity by bridging the yield gaps and shifting some of the area under these crops to other cereals and vegetables through integrated farming systems approach which optimize the use of natural resources. Currently, there is an imbalance between natural resources endowment and cropping patterns in the country. It is an irony that areas with less rainfall are net exporters of agricultural produce to areas with sufficient rainfall and untapped groundwater potential. A study on water footprint analysis and the trade of agricultural commodities especially for rice and wheat indicates that eastern India is a net importer from North India.

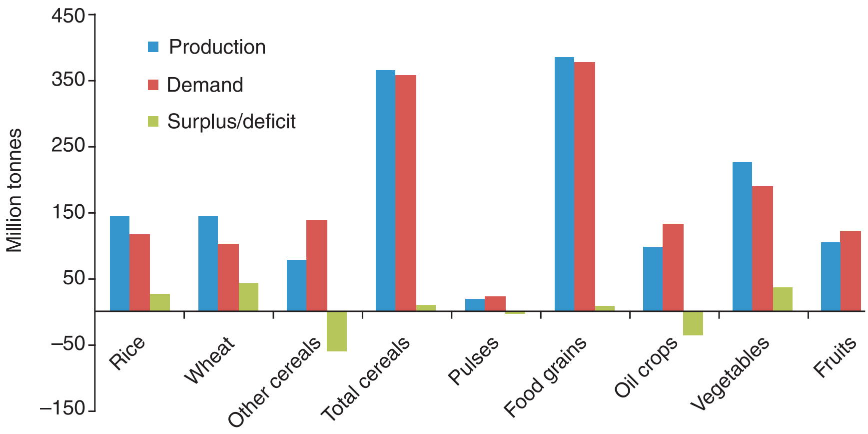

Fig.1. Projected domestic demand and production of different crop / crop groups by year 2050

Source: Amarasinghe, U.A., Tushar Shah and Anand, B.K. (2008) India's Water Supply and Demand to 2025/2050: Business-as-Usual Scenario and Issues. In: Strategic Analyses of the National River Linking Project (NRLP) of India Series 2, Proceedings of the Workshop on Analyses of Hydrological, Social and Ecological Issues of the NRLP (Eds. Amarasinghe, U.A. and Sharma, B.R.), Colombo, Sri Lanka: International Water Management Institute.500 p.

Managing water resources

In spite of large irrigation potential created (108 million ha), the gaps between gross sown and gross irrigated area and net sown and net irrigated area are about 105 million ha and 78 million ha, respectively. Out of the 62 million ha net irrigated area, 40 million ha is irrigated through wells while the rest is irrigated through canal systems and other sources. Research must address enhancing water productivity in canal systems. As the demand for water from non-farm sectors increases and availability to agriculture declines, the conflicts between upstream and downstream users may increase over time. A fallout of such process is the possible conversion of existing productive irrigated lands to rainfed lands.

Based on the growth trends, the net groundwater irrigated area could go up to 80 million ha. However, out of about 64 million ha potential for the country, by 2050 the net groundwater irrigated area could be about 50 million ha only. Heavy extraction of groundwater in low rainfall areas even for protective irrigation of rainfed crops is a matter of concern. A fallout of the excessive ground water use is the excessive power demand. There is a need to invest substantially by central and state governments on the issue of ground water use in rainfed areas. Southern and western India would be more at risk whereas central and eastern India offersgood scope for improving the underutilization of ground water resources and better prospects for ground water recharge due to higher rainfall. The decline in contribution to production from rainfed areas especially with <500mm rainfall due to various reasons could be overcome to a certain extent by ensuring timely sowing of crops or with intensive watershed management programmes with emphasis on *in-situ* conservation. In the regions of central and western India, the impact of variability could be reduced through development of new farming systems in which rice is replaced with less water demanding crops.

Many of the available water estimations have not factored variability/ change in the climate and their impact at farm scale and at meso-scale. With an anticipated change in rainfall and rainy days on the downside in southern and central India, the shift in sowing season to July/ August would have repercussions on the following rabi crop. Since the use of ground water in the canal commands is also not much in these states, methods to ensure successful sowing by early kharifneed to be ensured. On the other hand, northern (Punjab, Haryana) and western India (Gujarat and Rajasthan), which are expected to receive higher rainfall could be encouraged to shift to cropping systems which use less ground water. A detailed analysis considering the anticipated changes in water availability due to changes in land uses, climate change, changing choices for crops, population pressure could form the basis for watershed management programmes in future.

Maintaining soil health and productivity

The declining factor productivity of fertilizers in rainfed as well as irrigated areas is a matter of concern. Dryland soils are not only thirsty but also hungry. Ensuring optimum fertility of soils in the backdrop of declining animal population is a key challenge. The soil organic carbon, which is a seat of major soil processes and functions, is < 5 g/kg in rainfed soils whereas the desired level is 11 g/kg. Although about 80 million tonnes of crop residues are produced annually in rainfed areas, their recycling is not done due to competitive uses and burning. Organic matter addition into soil is essential to maintain the productivity levels and to improve use efficiency of inputs (Figure 2). Soil crusting in red and black soils; shallow depth, poor drainage in heavy textured soils of Madhya Pradesh, Maharashtra, Chhattisgarh, Northern Karnataka and Eastern Maharashtra; sodic soils of Haryana, Tamil Nadu and Andhra Pradesh; universal deficiency of macro- and micro-nutrients (Zn, B); are major issues. Change in rainfall intensity could cause more soil erosion. Unlike irrigated systems, harnessing the synergy between soil moisture and applied nutrients in rainfed crops is a major challenge due to erratic distribution of rainfall.

The soil type, soil depth, slope and fertility maps currently available with a resolution of 50,000 to 2,50,000 are not harmonious with farm level land use planning and also crop planning. Availability of high resolution maps will help institutes like CRIDA to develop suitable land use planning strategies for sustainable use of natural resources. Rainfed areas in India are bestowed with lot of potential to produce organic products as marginal and small farmers grow crops with low inputs available on their own farms instead of costly chemical fertilizers and pesticides. Existing farmers' practices of organic farming in these areas need to be refined for improving the quantity and quality of organic produce.

Climate change and climate variability

Climate projections show that atmospheric concentration of GHG would reach almost 685 parts per million (ppm) CO_2-equivalents by 2050. This is well above the concentration level of 450 ppm required to have at least a 50% chance of stabilising the climate at a 2°C global average temperature increase, the goal set at the 2010 United Nations Framework Convention on Climate Change (UNFCCC). Climate change and climate variability impact Indian agriculture in general and rainfed agriculture in particular. Rainfall is likely to decline by 5 to 10% over southern parts of India whereas 10 to 20% increase is likely over other regions. There is a probable decrease in the number of rainy days over major part of the country pointing at likely increase of extreme events. The recent ensemble models project that the frequency of extreme precipitation days (e.g. >40mm/day) are likely to increase. Annual average temperatures are expected to increase by 2 to 2.5°C. Warming is likely to be more over northern parts of India. A rise in night temperatures is also likely over India except some small pockets in the peninsular region.

At present in India, blue and green water availability is above the 1,300m^3/capita/year threshold. However, with climate change, blue-green water availability is estimated to decrease to less than 1,300m^3/capita/year, implying that by 2050, all of India could be exposed to water stress. Resilience to climate change will depend on increasing agricultural productivity with available water resources; refining technologies and timely deployment of affordable strategies to accomplish potential levels of arable land and water productivity.

Yields of wheat, rice and maize, the top three food grain crops in India will be affected adversely in 2050 and the most affected crop will be maize with close to 10% yield loss as shown in the Figure 2.

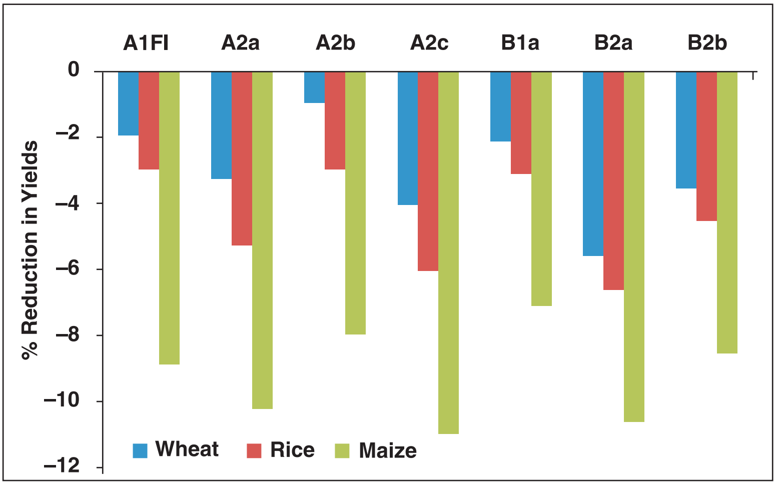

Fig. 2. Wheat, rice and maize yield changes (%) projections for 2050 under different scenarios relative to baseline scenario (1970-2000)
(Source: Climate: Observations, projections and impacts – India 2011 UK Met office report)

Irrigated rice yields are expected to reduce by 2050's. The likely yield loss would be 7% at country level. However at region level states like Punjab and Haryana the yield loss would be 15 to 17%. Temperature is likely to play a major role in reducing the yields of irrigated rice. Rainfed rice yields in parts of southern India(Andhra Pradesh, Tamil Nadu and Karnataka) are projected to increase by ~10 to 15%. However, in all other regions, projected reduction stands at 6 to 18% with more impacts in central and eastern India.

Crop simulation studies indicate a positive impact of future climate (combined change in temperature, rainfall and CO_2 levels) on the productivity of the soybean and groundnut crops. However, the rainfed yields of soybean and groundnut show significant positive association with crop season rainfall indicating the availability of water will remain a major limiting factor. While rainfed sorghum yields, on all India scale, are projected to decline by about 8% by 2050, irrigated kharif maize yields are likely to decrease by up to 18%. By 2050 climate change projected scenarios (HadCM3,A2), average crop water requirement of groundnut, mustard, maize and wheat is likely to increase by 6.4,6.6,4.7 and 6.0%, respectively, from the baseline of 1961-1990.

In livestock and fisheries sectors, increased heat stress associated with rising temperature may cause distress to dairy animals and possibly impact milk production. A rise of 2 to 6°C in temperature is expected to negatively impact growth, puberty and maturation of crossbred cattle and buffaloes. Global warming is likely to result in a loss of 15 million

Farmpond lined with RCC

tonnes of milk production by 2050. The low producing indigenous cattle are found to have high level of tolerance to these adverse impacts than high yielding crossbred cattle. Migration of fish species and shift in spawning activity of different fish varieties may happen due to the increase in SSTs.

Weather-based risk management in agriculture is another area where no substantial progress could be made so far due to lack of large databases, location specific nature of problems, diverse crop and animal production systems and insufficient understanding on frequency and intensity of weather aberrations. This calls for working with other stakeholders like IMD, NRSC, ISRO and SAC in a collaborative mode.

Institutional and policy issues

Livelihoods and sustainable production in rainfed areas are linked to the extent and health of Common Pool Resources (CPRs). Harnessing the contribution of these resources in reducing the emissions, ensuring ground water availability, biomass availability for grazing livestock, and meeting fuel/ firewood needs will help to increase small farm holders' income. The roles of various research organizations must be defined to avoid duplication of efforts. Extension system needs an overhaul with focus on on-farm participatory approach and increased use of Information and Communication Technologies (ICTs). Some states like Karnataka and Andhra Pradesh are proposing separate budgets for agriculture to meet these challenges in a holistic manner. The outcome of such initiatives needs to be keenly watched. However, the major challenge is to formulate a rational land and water use policy at national level and persuade the states for effective implementation.

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Operating Environment

Considering the Govt. of India's continued focus on inclusive economic development, the emphasis on dryland farming is likely to continue. Further Government of India is planning to invest 1% of the agricultural GDP on farm research. Several Government schemes on rural development and poverty alleviation focus on dryland agriculture, livestock development and small and marginal farmers. There is likely to be additional pool of financial resources available from private sector through Corporate Social Responsibility (CSR) which may be channelled to address issues related to climate change, natural resource management, environmental conservation and development of disadvantaged areas. This way, there is an overall favourable environment for supporting R&D in dryland farming, which is likely to continue even up to 2050.

Changing demand profile

Another major development likely to influence the research portfolio in dryland agriculture is the changing demand profile for different food commodities. With incomes rising, the future demand for cereal grains will be considerably low as compared to milk, meat and eggs. The estimated requirement for various food items by 2050 is given in Table 2.

High demand for meat and eggs means more production of livestock and poultry. The poultry sector in India is quite strong and capable of responding to the growing demand but the meat and milk sectors require considerable public investments in research, modernization of health care facilities, and cold chains besides a favourable pricing

Table 2. Demand for food (mt)

Food group	1999-2001	2015	2030	2050
Cereals	159	199	225	243
Fruits & Vegetables	108	160	208	257
Milk	66	104	146	196
Potatoes	25	37	46	58
Meat	5	9	17	27
Eggs	2	3	6	9

Source: Singh, R.B 2010 Towards a Food Secure India and South Asia : Making Hunger History. Documentation. National Commission on Farmers, New Delhi.

environment. Considerable production of milk and meat comes from the rainfed regions where livestock production is a major livelihood activity. Therefore, any investments to promote milk and meat production will favourably influence dryland farmers. The biggest challenge however is to meet the green fodder requirement. Currently fodder production is a neglected area both by the agriculture and animal husbandry departments, but to meet the growing needs of livestock products by 2050, considerable strengthening of research and extension services are needed in this area.

Impact of Trade Policies

Another issue is to meet the growing demand for pulses and oilseeds. The country has never been able to produce enough of these commodities to feed the population. In case of oilseeds, the policy environment has always played major role in influencing area expansion and investments by farmers. With growing affluence, the per capita edible oil consumption is likely to rise sharply leading to further surge in imports. Oilseeds being predominantly rainfed crops, the year to year fluctuations in yields are bound to remain due to monsoon aberrations. Therefore, a favourable trade policy along with investments on enhancing domestic production mainly through promoting critical irrigation during dry spells is essential. Private sector participation is likely to play major role in this sector. Increasing globalization of agricultural trade will differentially affect the profitability of different crops. Such impacts on the economy of oilseeds are already evident. There is a need to make rainfed agricultural seed production more competitive so that the welfare of farmers growing those crops is not compromised.

Pressure on natural resources

Changing food habits influenced by urbanization, globalization and accentuated by government policies also resulted in cropping patterns that do not fit well in rainfed areas. How these food habits change in the long run will have implications on use of natural resources. For example, increasing consumption of livestock products may lead to higher use of water. The productivity of water measured in terms of monetary value is much higher in other sectors compared to agriculture and hence the latter cannot compete with other sectors. Even with and without climate change, improving water use efficiency and expanding the access to water are critical to achieving the targets. There has to be a three-fold increase in water use efficiency in the next 30 years.

The per capita availability of land and average farm size are decreasing over time in the country. Although a reversal of trend may not happen in the immediate future, a need may arise to consolidate the land, at least in terms of operational holdings, as small sized farms may be a constraint to technology adoption. There is also a possibility of innovative institutional reforms such as contract farming, collective farming, and corporate farming. The decision making behaviour of each of these forms with respect to cropping pattern, technology adoption, investments, market participation etc. will vary and how farmers and governments respond will be a key factor in formulating the technology policy. If farms are operated as relatively larger units, there has to be an enhanced thrust on mechanization. If farms continue to be smaller in size as at present, mechanization research has to be complemented with research on institutional innovations that facilitate access to mechanization to the small and marginal farmers. In any case, CRIDA recognizes the need to work with and contribute to the evolution of appropriate institutional models that bring together farmers for harnessing the economies of scale in production and marketing. There is also a need to contribute to evolution of supporting institutions for better extension, market intelligence and liaison, legal safeguards, etc. that will require significant capacity augmentation.

Role of private sector

The role of private sector and civil society organizations in technology generation and transfer is increasing. While the former is actively engaged in the seed sector, the latter is playing a significant role in transfer of other kinds of technologies (water management, livestock-related etc.). Being a publicly-funded organization, CRIDA will be required to support and contribute to enabling, complementary, regulatory functions of the government. Private sector is obviously driven by profit motive and hence technologies related to NRM targeted to the marginal and small farmers may not attract private sector. In such cases, the government organizations have to play a key and leading role. Further, left to private sector alone, there is a danger of natural resources getting overexploited. CRIDA will have to advise the government in terms of appropriate technological, policy, institutional and regulatory mechanisms on use of natural resources for agricultural production.

Domestic policy environment

Some of the current problems related to resource degradation have their roots in the inappropriate pricing policies leading to inefficient use of inputs and resources. Now there is a growing resistance to subsidies and an increasing awareness on 'pay-for-service' paradigm. The future policy should balance the public good with viable enterprise promotion. While the role of advances in biotechnology and other sciences are well recognized, the path to realization of the potential they offer is not free from issues such as emergence of monopolies, reduction in biodiversity (genetic diversity), technology choice to farmers and long term implications to environmental health. Thus, maximization of the societal gains in the short as well as long term should be the guiding principle in determining the technology trajectory. Any agricultural research organization should contribute necessary inputs to policy formulation in this regard and CRIDA will be no exception.

There are also some unnerving and contradictory developments taking place in terms of what is being learnt from on farm or field experiences and what is happening in terms of organizational architecture. An important lesson learnt is that different technological and institutional interventions are effective only when they are implemented in a concerted manner warranting the convergence of different actors. Contrarily, some agricultural universities and ministries are further divided based on subjects thus disrupting the overall objective of convergence in different programmes in terms of focus, target areas, target groups and efficiency of delivery. While the challenges are many and complex, the resources available are not commensurate. Human and infrastructural resources have to be strengthened in terms of both quantity and quality.

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New Opportunities

THE recognition of rainfed agriculture as a high priority area by the Government of India is an important opportunity. Programmes like NMSA have identified several priority areas related to dryland farming and resources have been committed. Agricultural sciences must harness the advances in modern science tools and techniques like GIS, remote sensing, bioinformatics, nanotechnology, and information technology to support such major programmes. There has been a lot of work in delineating typologies (or agro-climatic/agro-ecological classification) using GIS. This can be effectively used in targeting interventions to rainfed regions. Remote sensing and GIS have potential to be applied in planning NRM interventions. For example, boundaries and locations for mechanical interventions within watersheds of different scales (micro, mini, catchment, basin etc.) can be done by employing the relevant RS/GIS tools. Active participation of communities will further help acceptance of the interventions.

An important opportunity for CRIDA is to tap the diversification of rainfed regions with region-specific models of integrated farming systems including livestock and fisheries. Such systems will help in cushioning the stakeholders against risks which are becoming more frequent in recent years. Opportunities also exist for diversifying to fruit, fodder, fuel wood and timber crops. Opportunities exist in the form of small holders taking up collective farming of single crops or form producer companies.

Deployment of biotechnological tools towards crop improvement is now closer to reality than a few years ago. CRIDA's experience in harnessing advantages of biotechnology could be successfully used for identification of candidate genes for abiotic stress tolerance and understand the mechanisms of tolerance. There are similar developments taking place within NARS and elsewhere. CRIDA will leverage these efforts by building partnerships and collaborations in developing crop varieties with desirable traits. Considerable investment was already made in developing infrastructural and human resources in this regard. Microbial strains have been identified for potential use in pest and nutrient management (phosphorus and zinc mobilization) and alleviation of heat stress.

A number of on-going development programmes such as the

MGNREGA, RKVY have provisions that can facilitate the adoption of labour-intensive technologies within rainfed agriculture. However, it has to be ensured that adequate technological backstopping flows to design and implementation of such interventions. Working together with various national and international agencies including civil society organizations is needed to harness synergy. For instance, within ICAR, if there is a platform to share research findings of different institutes and AICRPs relevant to rainfed agriculture, duplication can be avoided to get desired results in a planned way. To be globally competitive, there should be free exchange of knowledge and scientific manpower to harness latest tools and techniques in research. Some of the new science tools which CRIDA would like to use in future are discussed below.

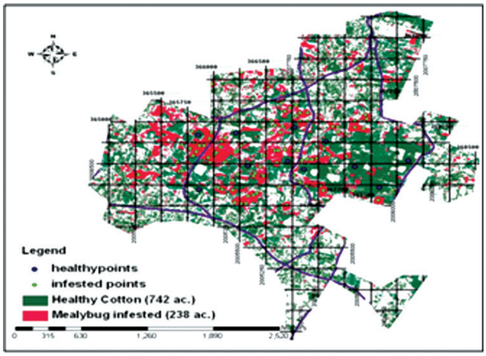
Decision support systems for contingency planning

Droughts and floods during crop season, extreme weather events like cyclones, cold wave and heat wave affect crop productivity and livelihoods of farmers. Such conditions require a continuous monitoring system. The district wise crop contingency plans developed by CRIDA in collaboration with other ICAR institutes, SAUs and line departments need to be implemented at field level based on the outcomes of such monitoring tools. For this, appropriate decision support systems (DSS) need to be evolved at different levels of execution. Such DSSs will help in refinement of the contingency plans based on the field-level lessons learnt. The district plans developed could be eventually web-enabled and query-based to make them user-friendly. Such efforts will help in timely interventions during aberrant weather conditions.

Agro-advisories & pest and disease forewarning

Long range and seasonal weather forecasting plays a significant role in agro-advisories and contingency planning in rainfed agriculture. Applying these forecasts at the block and village level is a key challenge for future. Receiving weather data from automatic weather stations across the country on line and formulation of agro-advisories for microlevel application and

A screen shot of agro-advisory



A GIS map of mealy bug infested cotton field

dissemination to target areas utilizing the modern ICT tools will aid in decision making. This requires substantial investments in technology upgradation, networking and capacity building. Simulation models will also be used for yield forecasting at regional and national level on regular basis including the impacts of weather deviations which will help in advance planning of crop choices. Forewarning models provide lead time for managing pest attacks and thus minimise crop loss. Model based DSSs for pest management in major crops such as rice and cotton will help in rational pesticide usage. Weather, crop phenology and pest/ pathogen biology are integrated in developing such DSSs.

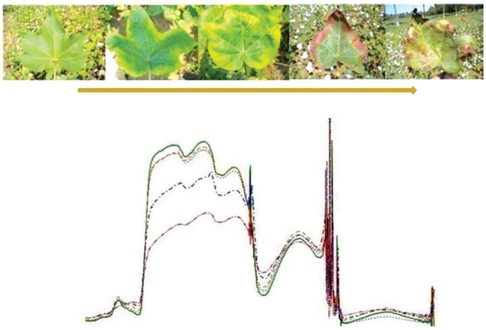
Integrated systems simulation modeling

Crop simulation modeling helps to understand behaviour of the crops in both current and future environments. What is needed is to integrate other components like natural resources, livestock, poultry and fishery sectors evolving a systems modeling approach. This helps in identifying sustainable integrated farming system models. Climate change is an emerging challenge for rainfed agriculture with expected impacts on the natural resources and production systems. We need information on regionally differentiated impacts to enable the local governments to plan suitable adaptation and mitigation measures. Down-scaling the global climate models to regional and district level and linking with crop simulation models to arrive at crop-specific and region-specific impacts is an immediate need. Systems models will also be used to estimate climate impacts, both current and future, on crop yields, pest and disease scenario and changes in water availability.

Remote sensing and GIS tools

Remote sensing and GIS tools are already widely used in rainfed agriculture, particularly in planning and monitoring of integrated watershed projects and land use planning. With expansion of the technology and availability of high resolution satellite imagery, many novel applications are emerging. Monitoring the status of natural resources over time, seasonal drought monitoring through Normalized

Difference Vegetation Index (NDVI), in season crop health monitoring over large areas for timely interventions on irrigation and pest management and locating water harvesting structures are some such applications. Remote sensing and GIS applications should be extensively exploited for real time crop contingency planning, and pest incidences at a higher resolution to develop location/region-specific forewarning systems. Under MGNREGS, substantial investments are being made on land and water development works. Use of RS and GIS will facilitate better location of such works and contribute to drought proofing. Planning of water harvesting structures like check dams and percolation tanks at mini basin level can be more efficient, if RS and GIS techniques are effectively used. Increasing use of these tools is found in land degradation, soil fertility and soil moisture mapping. These inputs are critical for successful crop planning in rainfed agriculture. Spectral libraries are unique crop signatures for identification of crop species and retrieval of biophysical parameters. Such libraries combined with ground based studies could be used for interpreting remote sensing data from airborne or space borne platforms for crop condition assessment and implementation of necessary management practices.



Hyperspectral characterization of leaf hopper damage in cotton

Nanotechnology and hydroponics

Modern science tools such as nanotechnology will be exploited to develop a variety of applications in rainfed agriculture. These include improved seed germination, soil moisture conservation, nanofertilizers, nano-biosensor based diagnostics for detection of plant stresses and nanocarriers for plant and animal health care compounds. Such products and processes are capable of delivering nutrients and other agri-inputs judiciously in appropriate quantities at required time thus increasing input use efficiency. Pesticides containing nano-scale active ingredients are already in the market. Pesticide particles of about 100 nm prevent spray tank filters from clogging, and also mix completely in water. Research is on to develop total “Smart Field System” using motes that automatically detect, locate, report and apply water, fertilizers and pesticides - going beyond sensing to automatic application. By deploying smart dust, the environment is sensed and implements adjust automatically. A nanotech-based soil binder called SoilSet which is quick setting mulch and binds the soil arresting erosion is already in the market. Nano-scale iron has been applied to soil to clean up heavy metals. Novel nanocomposites have been synthesized which can hold several hundred folds moisture to their volume and thus help in drought management. Geohumus is a soil enhancer with water storage capacity with a lifetime of 3 to 5 years. Exciting developments are possible in this field with significant impact on rainfed agriculture.

In the area hydroponics the vision of CRIDA will be to develop technology in pure soilless multi-tiered culture wherein yield maximization can be achieved through high precision nutrient management. CRIDA's vision will be to integrate nanotechnological sensor based input management to packages which will be highly precise, site and crop specific and will considerably increase the use efficiency and reduce wastage of various inputs.

Precision agriculture

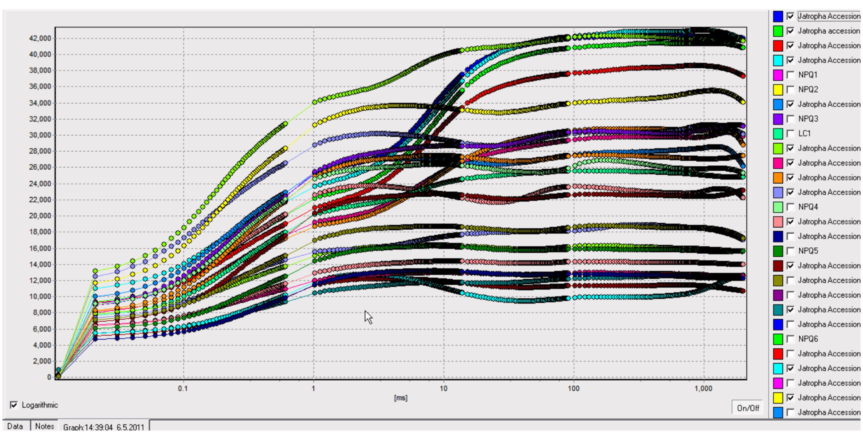
In the area of precision agriculture, the vision of CRIDA will be to effectively develop a completely automated Global Positioning System based agriculture operation support with very high degree of precision and also put to use big data and its analysis in this area. The vision is to develop a comprehensive repository of information in the form of a database with quick search and retrieve capability, such precision and highly downscaled location and crop specific data will be used to assist developing models for precision agriculture and also will be used to model crop behaviour over time and different climate scenarios. CRIDA will strive to develop packages in precision agriculture that will result in "prescriptions" for farmers that are developed through statistical models and algorithms. The support system will be downloaded from the cloud to hand held devices tablet computer or attached devices directly to the farmer's tractor. That tablet computer in turn will communicate with the tractor's planting machine, telling it how to vary the density of the seeds it plants as it carries out the field operation. In this way we at CRIDA will work towards using the whole area of data science and decision support as really having the possibility of changing the face of agriculture.

High throughput crop phenotyping

The era of post genomics has been ushered in with vast knowledge about the genome sequences of various crop species during recent years. It is now increasingly easier to sequence and map genomes, giving scientists access to information. Nevertheless, coverting this vast information to field application has remained a bottle neck. CRIDA is developing next generation research tools which will be applied to deep probe plant function and performance, under controlled and field conditions. Under NICRA, scientists plan to undertake high throughput precision phenotyping. State of the art phenotyping platform with automated non destructive imaging based scan analysis of crop growth and development will be developed to speed up screening for drought and other abiotic stresses. The platform will seamlessly integrate plant genomics with phenomics. Trait based physiological dissection of multiple stress tolerance will be followed to develop sound selection indices. Traits will be combined in various selection indices to assist breeders to produce desired phenotype for the specific agro climatic conditions. In addition, association mapping analysis between genotyping and phenotyping data will be done which will help in identification of QTLs involved in multigenic quantitative traits such as yield and grain quality. These quantitative traits will be bridged with specific traits such as drought and heat tolerance to achieve increased productivity at field level.

Molecular biology and bioinformatics tools

Multiple abiotic stresses are a key challenge for rainfed crops in future. In the same season, crops can face drought in early part and water logging in the later due to erratic rainfall distribution. Heat stress is another factor which could influence crop yields particularly



OJIP chlorophyll a fluorescence transients of Jatropha accessions during rabi season. Molecular techniques offer hope to evolve crops tolerant to multiple abiotic stresses. Chlorophyll a fluorescence can be effectively used to study drought tolerance and also do rapid screening of large amount of genotypes to identify drought tolerant lines to be used for breeding purpose to evolve tolerant varieties. CRIDA is already actively working on transgenic crops for enhanced drought tolerance. The institute has produced transgenic sorghum with mtlD gene which is undergoing field trials currently. Under NICRA, CRIDA along with other partners proposes to prospect and mine genes conferring tolerance to multiple abiotic stresses from different crops, wild relatives and land races. PCR based approach for functionally proven genes and subtractive hybridization for isolation of novel genes will be the two key strategies to be followed. Enormous amount of data generated in the post-genomics era needs to be sifted for specific useful information using computational and bioinformatics tools to comprehend basic processes and mechanisms involved in conferring such resistances. This knowledge could be used for high-throughput phenotyping and development of stress tolerant genotypes.

Our vision in the area of informatics will be to model multiple sources of genomic data within a common abiotic stress response framework using big data and analysing it by machine learning tools. We will aim to gain new insights into genetic networks and in multiple abiotic stress tolerances mechanisms. Some of the areas we will develop expertise in will be in methods and software for de novo assembly, whole genome and target region re-sequencing with specific reference to drought and heat stress in crops. Big Data analysis, genome phylogenetic analysis, transcriptome analysis, small RNA research areas will be targeted. Metagenomics Sequencing and Data Analysis in epigenetics related to water, heat and salinity stress in crops will also be stressed upon.

Conservation agriculture and integration of resource conservation technologies

In recent years, conservation agriculture (CA) has emerged as a new approach for resource conservation and to enhance agricultural production sustainably amidst growing concerns of resource

Conservation agriculture

degradation, decline in soil quality, low factor productivity and climate change. Although CA is being practiced in over 130 m ha of cropland worldwide, much of it rainfed, its adoption is limited in India, particularly under rainfed conditions. Some key challenges of CA include development, standardization of management practices, seeding and harvesting devices with minimal soil disturbance and with residues on soil surface and effective control of weeds for important rainfed production systems. Availability of sufficient amounts of crop residues is a major issue in rainfed ecosystems due to competing uses of crop residues as fodder, as drylands host large livestock population. Conserving rain water is key to successful rainfed agriculture but limited availability of residues is a challenge and calls for innovative solutions in the coming years. Site specific and production system specific development of CA practices and their scaling up is an emerging opportunity for efficient conservation of resources and enhancing the productivity in the years to come.


Retention of crop residue in maize-horsegram cropping system

Resilient rainfed productions systems and landscapes

Erratic monsoons and climatic risks (e.g., droughts, floods) make rainfed agriculture highly risky, vulnerable, and less resilient necessitating a different outlook and strategy. Impact of climate variability and climate change on agricultural production systems is happening in many parts of the country. Building resilience in agriculture and increasing the adaptive capacities of farmers to cope with climate extremes are pivotal to ensure food and livelihood security of millions of small and marginal farmers in changing climates. Climate resilient agriculture is a recent approach that has achieved prominence, given the


Soil erosion in Red soil

adaptation and mitigation challenges facing humanity. Increasing agricultural productivity to support increased incomes, food security and enhancing the adaptive capacity at multiple levels (from farm to nation) are important components of climate resilient agriculture and the relative priority of each objective varies across locations, with greater emphasis on productivity and adaptive capacity in low-input smallholder farming systems.

Actions to build adaptive capacity are varied and diverse, but consist of building ecosystem services in agricultural systems that enhance resilience, through soil, water and plant nutrient management, as well as improved on-farm water storage and irrigation, access to crop varieties that are more tolerant of heat, droughts, floods and salinity, diversification of farm enterprises (including mixed crop and tree systems) and building the capacity of institutions to enhance collective action, disseminate knowledge and undertake local adaptation planning. In view of the pervasive influence of the climate change there is a need to move from individual farmer to landscape perspective, with either village or watershed as a unit. Strategies that enhance climate-resilient agriculture are the most appropriate starting point for sustainable agriculture and the sustainable intensification approach is compatible with climate resilient agriculture as intensification consists of efficient and intelligent use of resources which leads to adapting to climate change and results in lower emissions per unit of output. Reducing the emissions from the production system is an important component and there is a need to reduce the carbon foot print of rainfed systems in the years to come without compromising the productivity.

Combating extreme climatic events

In the face of increased frequency of climatic extremes due to climate change in the coming decades, CRIDA's vision is to monitor, predict and mitigate the adverse impacts of extreme climatic events through suitable interventions. Monitoring and forecasting of climatic extremes can be achieved through active collaboration with national and international institutes. As weather data is still sparse, accurate interpolations between existing weather stations for creating virtual weather station for any location are to be developed for improved short term forecast of climatic extremes and their dissemination to farmers through SMS. Real time monitoring of slow onset climatic extremes like drought will be developed for better mitigation and adaptation. Index insurance products for all the rainfed crops, livestock and horticulture systems will be developed as adaptive strategy for climate change. Mechanisms for harvest and post harvest losses due to extreme climatic events will be addressed. Value-added weather management services (including contingency plans, climate predictions and pest forecasting systems) for reducing production losses will be introduce at field level. Integrated multi-hazard early warning systems to support more timely and better coordinated response to climatic shocks will be developed. Rural climate information services will be strengthened so as to make dryland farmers well educated about climate related extremes and their mitigation.

Innovations in technology transfer

Technology transfer is one of the weakest links in rainfed agriculture. The public sector extension system is unable to meet the demands of rainfed agriculture which is quite diverse and challenging. The only way is to build the capacity of the community based organizations and farmers groups so that the knowledge acquisition and transfer processes can go in the hands of the community. CRIDA is among the first to recognize the importance of bringing together diverse skills and strengths of different organizations for accelerated technology transfer. This will help shorten the research and adoption lags.

There are number of successful cases of technologies being adopted faster when disseminated through farmer groups rather than through individuals. With several successful pilots being available on use of ICT

Phenomics facility

in farm extension, this method of reaching farmers is going to remain the mainstay in future. The setting up of National Optical Fibre Network and linking up gram panchayats with high speed network connectivity under Digital India programme and setting up of information kiosks provides opportunities for seamless data transfer between the field and lab and vice-versa through the mobiles or kiosks and also face-to-face communication to cater the needs of the stakeholders. This is an opportunity and as well as a challenge before the agricultural research community to make the information available to the communities as per their requirements and in a form that is easily understood and delivered for a wide range of literacy levels as well as languages. With the faster spread of mobiles there is a need to move towards mobile based personal communication fom kiosk based information dissemination. With 3G and 4G technologies in the offing, detailed text and pictures can be transmitted through mobiles. Research on use of ICTs for monitoring and developing early warning systems for hazards such as drought, floods and other extreme weather events has to be taken up.

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Goals and Targets

Goal	Target	Strategies	Output
Doubling of farm income and productivity in rainfed areas from the current level of 1 to 2 t/ha	Agro-climatic characterization in relation to crop, livestock, pest and diseases.	Vulnerability assessment of rainfed production systems in different Agro ecological regions	Vulnerability assessed for major agroecological zones and rainfed production systems.
		Integrated simulation modeling for rainfed crops including soil, water, plant interactions	Simulation modelling of crops and farming systems for forecasting impacts of various biotic and abiotic stresses.
		Characterizing host-pest interaction in relation to weather	Crop specific decision support system on pest-weather relationship prepared.
		Assessing the intra and inter-seasonal weather aberrations on long-term basis and predicting contingencies	Near real time monitoring of weather and operationalization of contingency measures
	Rainwater management *in situ* and *ex situ.*	Estimating of harvestable surface runoff for different rainfall scenarios with special reference to deficit and high intense rain events	Spatial & temporal rainwater budgeting for seasonal crop planning in a participatory mode.
		Multi-location testing and standardization of erosion preventing/arresting technologies	Control of land degradation by arresting soil loss and run-off.
		Development and evaluation of location/region specific, in-situ and ex-situ water harvesting technologies	Higher rain water productivity through *in situ* conservation and ex-situ harvesting of rainwater for supplemental irrigation.
	Diversification of rainfed agriculture.	Development of cost effective, location specific integrated farming system modules	Integration of trees-crop-livestock in the farming system mode.
		Promotion of high yielding fodder crops and varieties for increased productivity	Higher area under annual & perennial fodder crops achieved for ensuring livelihood security of small and marginal farmers with focus on small ruminants.
			Public-private-partnership models involving fruit, medicinal, aromatic and dye-yielding plants.

Climate Resilient Agriculture	Application of novel science tools for enhancing tolerance to abiotic and biotic stresses.	Identification/evaluation of crop varieties and breeds tolerant to various stresses	Crop varieties, livestock breeds tolerant to biotic and abiotic stresses evaluated/ identified.
		Carrying out basic and fundamental research for better understanding of stress tolerant process	Elucidation of abiotic and biotic stress tolerant processes.
		Development of technologies that can enhance the crops and livestock to adopt and mitigate aberrant weather conditions	Enhanced coping and adaptive capacity of crops and livestock to aberrant weather conditions.
	Higher resource use efficiency through conservation agriculture.	Identification of location specific crops and cropping systems	Productivity and income stability in rainfed production systems enhanced.
		Development of cost effective water and nutrient management technologies using nanotechnology tools	Increased mitigation through site specific water and nutrient management.
			Energy efficient production systems developed.
			Systems identified with improved carbon sequestration capacity.
			Reduced GHG emissions through biomass recycling and alternate land use systems.
	Improved small farm mechanization.	Design and development of new, cost effective tools and equipments	Reduction in drudgery particularly women.
			Timely and energy saving farm operations through improved machinery.
			Value addition to farm produce and reduction in post harvest losses.
	Human Resource Development.	Organizing training programmes, field schools, demonstrations, hands-on training programmes	Increased awareness among primary and secondary stakeholders on drought and its impact.
			Capacity built to combat climate change.

Human Resource and Infrastructure Needs for Achieving Proposed Goal

The institute is already bestowed with scientists representing a wide range of disciplines to address the core issues of rainfed farming in the country. However, to develop and evaluate technologies using cutting edge science tools viz. nanotechnology, bioinformatics, precision farming, etc., there is a need to expose the existing manpower at reputed national and international institutes for hands-on training for learning and updating their skills and knowledge. Further, considering the requirement of addressing the multitude of problems arising due to on and off-farm risks, especially under climate change scenario, there is need to enhance the scientific and technical cadre strength of CRIDA by at least 25%.

For carrying out cutting edge research in the areas of nano-technology, precision agriculture and bioinformatics, there is need to create state of the art laboratories and related infrastructure. Already efforts are being made to establish infrastructure and equipment for conducting research on impacts of climate change on Indian agriculture and to develop suitable adaptation and mitigation strategies and these efforts have to be doubled in order to meet the proposed goals and targets. There is a need to extend these facilities to AICRPDA and AICRPAM centres at regional level. For on-farm demonstration and technology communication, ICT infrastructure needs to be upgraded. There is also a need to develop appropriate communication and information network infrastructure for outreach programmes.

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Way Forward

Raising productivity of rainfed crops is a challenge requiring concerted efforts of many actors with a regionally differentiated and farmer's income approach. CRIDA sees itself primarily as a technology provider and as a facilitator of technology adoption and diffusion. Necessary in-house capabilities will be built and strengthened in terms of physical infrastructure, human resources and an efficient enabling administrative environment towards achieving this goal. More efforts will be made to maximize returns on investment in research and robust monitoring and evaluation mechanisms. Special emphasis will be laid on using social science skills in setting up the research agenda and to convert the outputs into societal outcomes. Impact assessment will be made mandatory for all programmes.

Location specific research and efficient delivery will be two guiding principles for the next few decades. Efficiency is directly connected to the sustainability of the system, competitiveness, climate change adaptation and mitigation and better utilization of human and financial resources. The proposed goals and targets will be achieved in a phased manner dovetailing the research accomplishments with the development programmes and public policies. During next decade, primary focus will be laid on rain water harvesting and soil health management in achieving the goal of productivity enhancement. Efforts will be made to promote technologies and policies to encourage water saving through promotion of rain water harvesting through intensive R&D and upscaling successful field experiences. A vulnerability map at regional level considering frequent extreme weather events has to be developed which will be a guiding document for crop diversification and risk management. Special attention will be given for bridging yield gapsin pulses, coarse cereals, and fruits & vegetables. Integrated farming system modules for different production environments will be attempted on priority for risk-proofing of small and marginal farmers. Efforts will be made to disseminate the off shelf technologies through action research building on the experiences of NATP and NAIP programmes.

In the coming decades, considering the growing vulnerability of Indian Agriculture to climate change, priority will be to develop adaptation and mitigation strategies to bring resilience. High throughput phenomics platforms will be used for characterizing germplasm for abiotic and biotic stress tolerance. Similarly, remote sensing and GIS applications will be exploited for natural resource characterization and land use planning. Nanotechnology based products and processes will be developed for application in agriculture. Focus will be laid on basic and strategic research for understanding the soil-water-crop interactions. The institute will strive to forge linkages with development departments at centre and state level.

Surface and subsurface water management strategies and rain water harvesting efforts will help to augment the ground water. Improved soil health and agro-advisories and decision support systems for abiotic and biotic stress management will stabilize crop productivity. Similarly, nanobioformulations will help in drought management, water and agri-input use efficiency and induction of host resistance. Several research strategies for improving resource use efficiency in rainfed areas will be demonstrated on large scale. Small farm mechanization is another important area that will be addressed considering the uneven monsoon patterns (realizing the criticality of timely agricultural operations), drudgery and acute shortage of labour for agriculture. Development of new farm machinery tools for energy management and precision agriculture will be yet another focussed area.

Monitoring of extreme weather events, forewarning, and development of weather indices for insurance for major crop/horticulture/livestock systems will be taken up in partnership with public sector insurance companies. Development of decision support systems for weather based monitoring of major pests and diseases will enable timely intervention to reduce crop losses. Agromet Advisory Services will be taken to village level using remote sensing and ICT. Diagnostics such as nano biosensors, etc. for detection of abiotic and biotic stresses developed in different programs will be used for early diagnosis and timely intervention.

On the policy front, CRIDA will strive to initiate a national mission on rainwater harvesting by working closely with MoA and MoRD. Out of 114 BCM water available as surplus, about 28 BCM is available for supplemental irrigation to irrigate an area of 25 million ha during normal monsoon year and 20 million ha during drought year. The envisaged programme will thus help to protect crops in rainfed regions from prolonged dry spells. Research efforts in other areas will help to shape new national policies in terms of promotion of health food formulations based on coarse cereals, crop diversification, resource use efficiency, farm energy management and soil health management. The integrated farming systems will give a better penetration opportunity for risk management through efficient weather based insurance products.

Another important domain is the huge pool of human resources trained under various research programmes which will be available to cater to the needs of the national human resource.

The R&D efforts envisaged will significantly contribute directly or indirectly to the mandates of the eight national missions of Government of India on climate change. Significant contribution will be towards achieving the goals of National Mission for Sustainable Agriculture. CRIDA will also contribute significantly to the National Mission on Strategic Knowledge for Climate Change in terms of impacts and challenges, improved climate modelling, and increased international collaboration. The outputs also will help achieve goals of other missions such as National Solar Mission (some of the research programmes like rain water harvesting and lifting will harness solar power); National Mission for Enhanced Energy Efficiency (nanotechnology tools to improve efficiency of farm implements with enhanced energy efficiency); National Mission on Sustainable Habitat (NICRA and other programmes targeting carbon sequestration and reduction of GHG emissions); National Water Mission (rain water harvesting and ground water recharge promotion increasing water use efficiency and reducing scarcity). Also programs/models developed through R&D activities for convergence of various schemes of government will help in delivering the desired outputs to the stakeholders in a consolidated approach which can be further scaled up.

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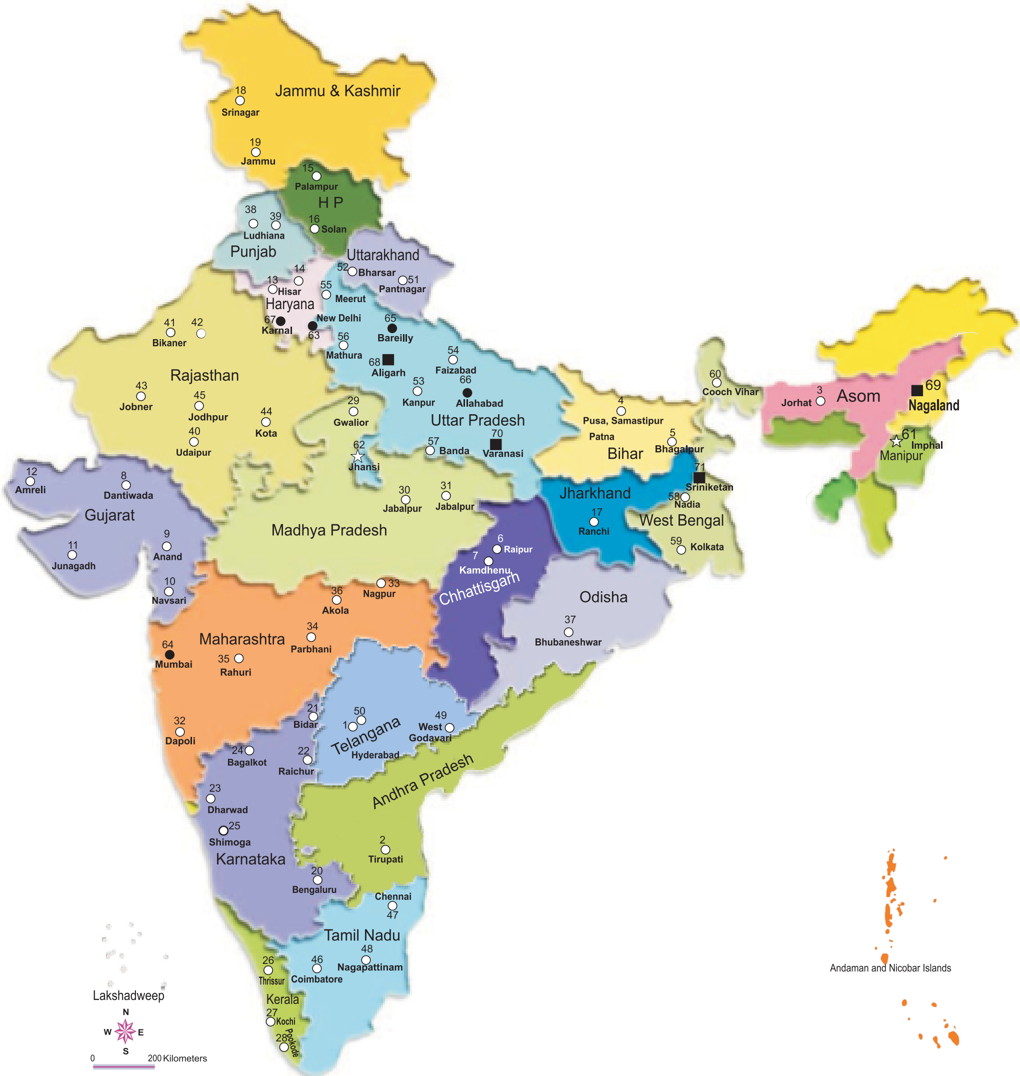
Agricultural Universities



LEGENDS

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Central Universities with Agricultural faculties	■
Central Agricultural Universities	☆
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