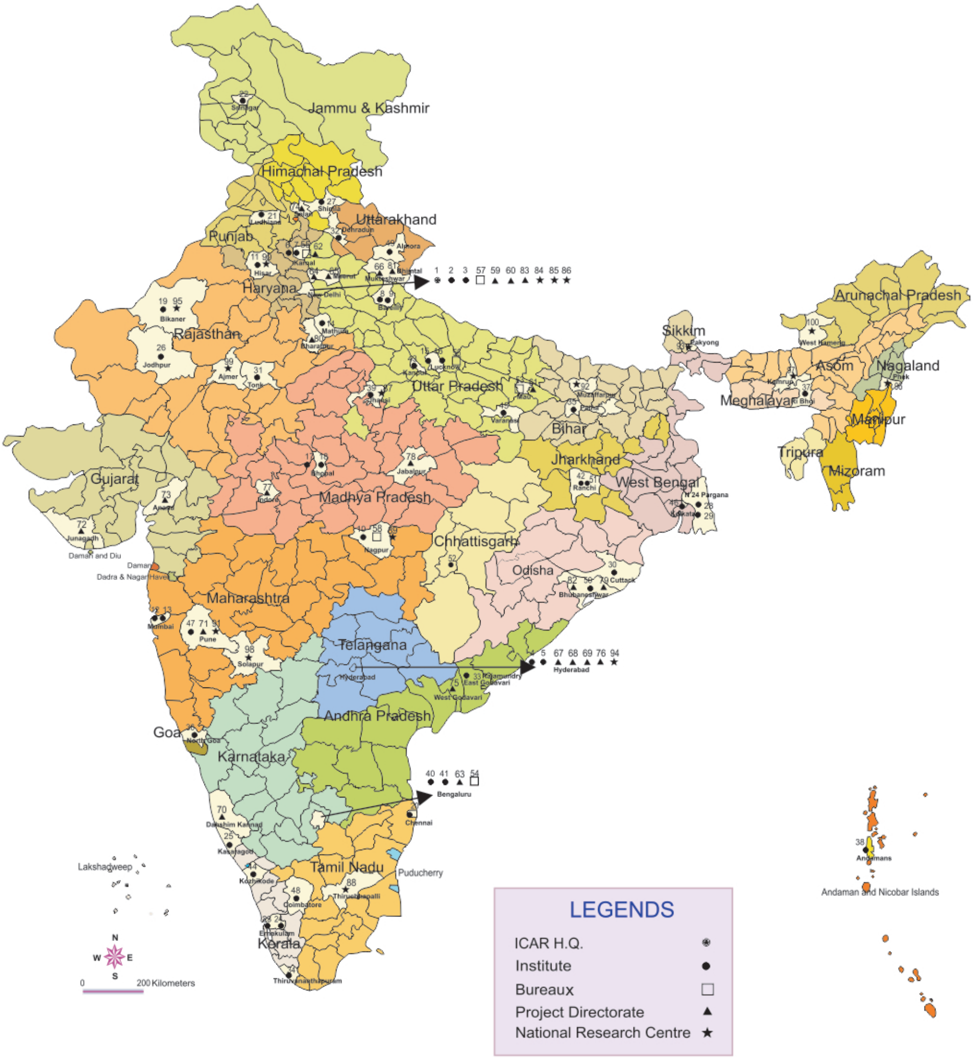
Vision 2050

Sugarcane Breeding Institute

Indian Council of Agricultural Research

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Institutes, Bureaux, Directorates and National Research Centres



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

Vision 2050

Sugarcane Breeding Institute (SBI)
(Indian Council of Agricultural Research)
Coimbatore, Tamil Nadu
www.sugarcane.res.in

Printed : July 2015

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-Sugarcane Breeding Institute (SBI), Coimbatore has been prepared, based on a comprehensive assessment of past and present trends in factors that impact agriculture, to visualise scenario 35 years hence, towards science-led sustainable development of agriculture.

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

(S. AYYAPPAN)
Secretary, Department of Agricultural Research & Education (DARE)
and Director-General, Indian Council of Agricultural Research (ICAR)
Krishi Bhavan, Dr Rajendra Prasad Road,
New Delhi 110 001

Preface

The Indian sugar Industry came into being at Saran in Bihar during 1904 with the establishment of the first vacuum pan process sugar plant. Research on sugarcane to evolve suitable varieties for Indian conditions began almost simultaneously with the establishment of the Sugarcane Breeding Station, now the ICAR-Sugarcane Breeding Institute, at Coimbatore, in 1912. A major breakthrough in sugarcane breeding was the evolution of Co 205, obtained by crossing the cultivated sugarcane (*S. officinarum*) with the wild species (*S. spontaneum*), which was released for cultivation in subtropical India in 1918. Since then more than 2,900 Co clones have been evolved by the Institute. The present day wonder varieties, evolved and released by the Institute, are Co 86032 for tropical region and Co 0238 for subtropical region of the country. A modest estimate is that Co 86032 occupies over 1 million ha in tropical India. Similarly, Co 0238 has already occupied more than 2.5 lakh ha during 2014-15 in subtropical India, within five years of its release during 2009. The research efforts of the Institute had led to spectacular growth in cane area and sugar production in the country during the last eight decades. There had been a nearly fivefold increase in cane area and tenfold increase in sugarcane production during the period. The number of sugar factories went up from 29 to over 600, of which 513 are currently operational. The ICAR-SBI also played a key role in developing a large number of location-specific varieties by the State Sugarcane Research Stations through its unique National Hybridization Programme. At present, the varieties developed by ICAR-SBI and the state research stations with ICAR-SBI support occupy more than 90% of the cane area in the country.

Researchable Issues

During 2012-13, more than 50% of the sugarcane area in the country was occupied by three major varieties namely Co 86032 (tropical India), CoS 767 and CoSe 92423 (subtropical India). These varieties, released more than 15 years back, together with a few other varieties occupy 70% of total area under sugarcane. These figures indicate the slow replacement of old varieties, the main reason being the requirement of huge quantity of seed per unit area. At present, transportation of sugarcane seed is a difficult task as a truck load of sugarcane material is required as seed for planting one hectare of area. At a modest estimate, approximately 14.42 Mt of sugarcane is used as seed to plant 2.22 mha area in the country. Single bud sett planting, spaced transplanting (STP) and polybag / pro-tray nursery are some of the options available, by which seed requirement could be reduced from 40% to 83%. The Settling Transplanting Technique (STT) is already in practice on a small scale in tropical states. Adoption of proposed STT of sugarcane cultivation will be advantageous in terms of reduced seed rate to $1/6^{th}$, 10 to 20% higher cane yield, faster multiplication and replacement of desired varieties, development of small entrepreneurs, and may be an instrument in Attracting and Retaining Youth in Agriculture (ARYA).

Concerted research efforts are required to meet the projected sugar requirements of 2050. Sugarcane is a cross pollinated crop and the present day varieties are of varied heterozygosity levels (<100%) involving three *Saccharum* species (S. *officinarum*, S. *Spontaneum and* S. *barberi/sinense*). Station-wise inbreeding (i.e. crosses among the clones developed at a particular station) has further reduced the heterozygosity levels of the sugarcane varieties. As a result, the variance among the progenies of crosses has reduced to the experimental error level at majority of sugarcane research stations. In order to meet the future demands from the presently available area, there is a need to exploit the dominance variance (heterosis) to the maximum possible level. By adopting the STT method combining with true seed hybrids, it would be possible to change the mode of transportation of sugarcane-seed from **Truck to Pocket**. I see it as the future of sugarcane agriculture in the country. During the Institute Research Committee meeting on June 5, 2015, the ICAR-SBI has decided to initiate work in this direction after a brain storming discussion.

The major problem of sugarcane agriculture in Western UP, parts of Central UP and Haryana is summer planting of sugarcane, i.e. after harvesting of wheat crop. Summer planted sugarcane crop results in 25-40% reduction in yield in comparison to spring planting, whereas autumn planting produces about 25% higher yield over spring planting. There is a need to popularize autumn planting of sugarcane in the above mentioned regions with intercrops in order to improve the productivity (>50%) and sugar recovery to ensure higher income to the farmers. For achieving this, collaborated efforts of sugarcane, pulses (ICAR-IIPR), vegetables (ICAR-IIVR) and oilseeds (ICAR-DRMR) based Institutes will be helpful in identifying suitable varieties of these intercrops for different sugarcane growing regions.

Precision farming, drip irrigation, fertigation, soil health, mechanized sugarcane farming system, development of varieties with better water/ nutrient use efficiency, etc. are some of the other issues which will require attention in future. Biotechnological approaches are also incorporated for the identification of sugarcane specific genes implied in stress resistance and agronomic traits, and for their deployment in genetic improvement through transgenic and molecular breeding approaches. New management strategies incorporating genomic and proteomic approaches will be continued against fungal diseases especially red rot. Anticipatory research to combat the effects of climate change and bioethanol production are given due focus. Efforts on haploidy and apomixis will be initiated for their judicious application in sugarcane improvement.

Policy Issues

Sugarcane research and development personnel should feel glad that unlike other crops, there is surplus sugar production in the country. Of course, excess sugar production has led to many related problems such as lower ex-factory price of sugar due to which sugar factories are not in a position to pay cane price to farmers. This has resulted in huge cane price arrears in all the major sugarcane cultivating states. As on 28th February 2015, the cane price arrear was ₹ 18,592 crores. To deal with this excess production of sugar, there is a need to divert a part of sugarcane juice for purposes other than sugar. The most feasible diversion of sugarcane juice is towards production of ethanol, spirit and potable liquor. I see a great potential in ethanol production directly from sugarcane juice as well as bagasse. Depending upon the sugar requirement in the country, the quota for sugar production may be fixed for each mill as per the capacity of the mill and distillery. The rest of the juice can be diverted for ethanol production. This will help in - increase in availability of renewable energy in the form of ethanol, lesser emission of carbon gases by vehicles and hence reduction in air pollution, saving in foreign exchange for the exchequer, and better economic health of sugar industry. For producing ethanol directly from sugarcane juice, essential changes in the law have to be made.

Bagasse could be utilized either for co-generation or for production of second generation ethanol. There is a need to have a state level policy in this regard. The Institute has developed high bio-mass producing energy canes, which can be grown on marginal/barren lands and the same could be utilized for co-generation or for ethanol production.

A large number of intercrops can be grown with sugarcane. Intercrops give mid-season income to the farmers, help in managing weeds and improve soil fertility. If intercrops are taken in autumn planted sugarcane replacing the summer planting of sugarcane, then it will also result in increased cane yield (>50%) and better sugar recovery in Western UP, Haryana and Central UP. However, in spite of these well known advantages, the area under autumn planting of sugarcane with intercrops never crossed 10% in major sugarcane growing states. The reason is lack of assured marketing for the produce of intercrops. If sugar factories come forward for further diversification in the form of packed products, particularly pulses, vegetables and oil seeds, the area under autumn planting of sugarcane will bound to increase. It will also diversify the activities of the sugar factories.

Since sugar industry is rural based, another possibility of diversification in the activities of sugar factories in the country is in the field of dairy technology. Sugar factories can process the milk and if desired may go for other dairy products.

The Institute has been catering to the needs of the farmers and sugar industry in the country since its inception in 1912. I am confident that with the available resources, the Institute will stand tall to fulfil the demands of its clienteles and there would not be any shortage of sugar in the country even during 2050. The Institute is also ready to contribute in a big way on technological fronts such as renewable energy requirements.

The assistance rendered by all the scientific staff of the Institute and Dr. P. Murali and Dr. A. Bhaskaran, in particular, in preparing this document is gratefully acknowledged. I am extremely grateful to Dr. S. Ayyappan, Secretary, DARE and Director General, ICAR, Dr. Jeet Singh Sandhu, Deputy Director General (Crop Science) and Dr. N. Gopalakrishnan, ADG (CC) for their guidance, support and constant encouragement.

(Bakshi Ram)
Director

Contents

Context

Sugarcane is the second most important industrial crop in the country occupying about 5 million hectares area. India is the second largest producer of sugar after Brazil. Over 5 million farmers are involved in the cultivation of sugarcane. Sugar industry contributes significantly to the rural economy as the sugar mills are located in the rural areas and provides employment for nearly 4% of the population directly or indirectly. The various by-products of sugar industry also contribute to the economic growth by promoting a number of subsidiary industries. Sugarcane is emerging as a multi-product crop used as a basic raw material for the production of sugar, ethanol, electricity, paper and high value bio molecules, besides a host of ancillary products.

India is the second largest producer of sugar, our export share is marginal due to large domestic demands. Sugar is an essential item of mass consumption and the cheapest source of energy, supplying around 10% of the daily calorie intake. The importance of the sugarcane agriculture is that it is able to meet the huge domestic requirement, which otherwise would have necessitated massive imports. Domestic price of sugar in India is lowest among the world. The cost of Indian sugar production is estimated to be in the medium range higher than that of Australia and Brazil but lower than that of USA. In future, we may face stiff competition from Latin American Countries, Africa, and South East Asian countries where the cost of production of sugar is low.

Contribution to the Economy

The contribution of sugarcane to the national GDP is 1.1% which is significant considering that the crop is grown only in 2.57% of the gross cropped area. The contribution of sugarcane to the agricultural GDP has steadily increased from about 5% in 1990-91 to 10% in 2010-11. During the past two decades, the average annual growth of sugarcane agriculture sector was about 2.6% as against the overall growth of 3% in agriculture sector in the country (NAAS, 2009). Sugar industry contributes an estimated ₹ 4100 crores annually to national exchequer and treasuries of various state governments by way of excise duty and purchase tax on sugarcane and sugar.

Sugarcane has been projected as the crop for the future contributing to the production of not only sugar but biofuel and bioenergy as well.

Ethanol is a proven and environmentally safe alternative to fossil fuel and the use of ethanol in transport industry is ever increasing. The World Energy Council (WEC) expects that the transport fuel demand in next 40 years will come mainly from developing countries such as China and India where demand will grow by 200-300%. By a modest estimate the demand for petrol is likely to double to 64 million tonnes by 2050, considering the projected growth in commercial and domestic transport sectors. The import of crude oil to meet this requirement is likely to impact the country's economic growth seriously and alternatives have to be found. Besides, the country should achieve the mandated emission levels by 2050, which is possible only through the reduction in the consumption of carbon fuels. At present, blending of petrol with 5% ethanol is mandatory in the country which is a gross mismatch when compared with Brazil, where vehicles are operated with either 25% ethanol blend or 100% ethanol. In India also a policy shift towards higher ethanol utilization in energy sector is unavoidable. At present, ethanol is produced exclusively from molasses as direct conversion of sugarcane juice to ethanol is not permitted. To meet the growing demand for ethanol as a biofuel and other industrial and commercial use, the molasses route may not be adequate. Excess sugar production in the country also provides reason to produce ethanol directly from sugarcane juice. The ethanol requirement by 2050 at a modest 20% blending and other uses will be 20,000 million litres. This amounts to over 100% enhanced demand for sugar and 500% for ethanol. It may be necessary to consider establishing energy plantations exclusively for ethanol production from the sugarcane biomass. Since expansion of cane area is not possible, such plantations have to be established in marginal lands or waste lands for which suitable varieties and production technologies need to be evolved.

> By 2050, total white sugar demand may reach 48 Mt and the sugarcane requirement would be 550 Mt

By 2050, the population in the country is expected to reach 1.65 billion. At the present rate of growth in consumption, the requirement of sugar will go up from 23 million tonnes to 48 million tonnes. The sugarcane area is not expected to expand beyond the current 5 to 5.5 million ha and the enhanced demand has to be met by a similar improvement in sugarcane productivity and sugar recovery. This needs effective

> The institute has the world's largest sugarcane germplasm

strategies and careful planning taking into account the projected targets, factors affecting productivity and sustainability, environmental impacts, the resources available, the technology landscape and by setting priorities for research and development. The Vision 2050 of Sugarcane Breeding Institute has been developed in this context.

Research & Development

Sugarcane Breeding Institute (SBI) established in 1912 had been serving the sugarcane farming community of the country for more than a century through release of improved varieties and crop production-cum-protection technologies. The Institute is engaged in the development of superior varieties suited for the different agro climatic conditions prevailing in the country integrating conventional and the novel biotechnological approaches. Over 90% of the area under sugarcane cultivation in the country is occupied by the varieties developed by the Institute or varieties developed by the State Sugarcane Research Stations from the crosses made at SBI. The present ruling variety in the tropical region of the country is Co 86032 which occupies over 90% area in Tamil Nadu and over 50% area in Maharashtra and Karnataka and sizable areas in Gujarat, Telengana, Andhra Pradesh and Odisha. The annual gross value realised from this variety alone is estimated to be about ₹ 15,000 crores. The area under Co 0118 and Co 0238, the new varieties developed by the Institute is increasing steadily in the subtropical India. The Institute also conducts basic, strategic and applied research on various aspects of sugarcane varietal improvement, crop production and crop protection technologies. The sugarcane germplasm maintained by the Institute is the largest in the world and the only collection that has been characterised and documented. The Institute has a strong interface with the sugarcane farmers, sugar industry and the sugarcane development departments for the transfer of technologies developed by the Institute.

The Institute has one Regional Centre at Karnal, Haryana to cater to the varietal needs of the subtropical India. The Research Centre at Kannur, Kerala, houses the world's largest collection of sugarcane germplasm while the Research Centre at Agali serves as the National Distant Hybridisation Facility and the national off season nursery for the other mandated crops of ICAR.

Status of Technology Development

Before the advent of the Co varieties, the average sugarcane productivity in the country was less than 15 t/ha. With the spread of the Co varieties to the extent of 75% of the area in the country in 1935-36, the productivity was improved to 37 t/ha. So far the SBI had developed over 2900 sugarcane varieties since its inception, many of which have become popular varieties in different parts of the country. The world's first interspecific sugarcane hybrid between the cultivated sugarcane (*Saccharum officinarum*) and the wild species (*Saccharum spontaneum*) developed by SBI-Coimbatore in 1918 recorded 50% higher cane yield in undivided Punjab and United Province was the earliest demonstration of the use of a wild species in crop improvement. Some of the landmark varieties developed by the Institute are Co 205, Co 213, Co 290, Co 312, Co 313, Co 419, Co 527, Co 658, Co 740, Co 997, Co 62175, Co 6304, Co 6907, Co 1148, Co 1158, Co 7805, Co 7717, Co 89003 and Co 86032. These varieties have played a significant role in sustaining the growth and expansion of the sugarcane cultivation throughout India.


CoJ 64

The recent varieties released from the Institute include Co 99004, Co 2001-13, Co 2001-15, Co 0218 and Co 0403 for the tropics and Co 98014, Co 0118, Co 0237, Co 0238, Co 0239, Co 05009 and Co 05011 for the subtropics. The varieties developed by SBI had played a major role in the emergence, growth and sustenance of the Indian sugar industry.


CoC 671

The Institute also supports the breeding programmes of over 20 State Sugarcane Research Stations by extending the National Hybridisation Garden (NHG) facility. Several outstanding varieties like CoC 671, CoJ 64, CoS 767, CoS 8436, CoJ 83, CoPant 84211, CoLk 94184, CoSe 92423, CoSe 95422, CoS 88230, CoA 92081, CoV 92102, CoM 0265, CoH 119, etc. have been developed through NHG facilities. At present the varieties developed by SBI or the varieties developed by the state sugarcane research stations with the support of SBI occupy over 90% of the cane area in the country, with an average yield of about 70 t/ha.


Co 86032

Thus historically the contribution of SBI varieties in the growth of sugarcane agriculture and the sugar industry in the country had been most unequivocal. Besides, a large number of Co varieties have played an important role in the sugarcane agriculture in 28 foreign countries. 'Co' varieties had been used either for commercial cultivation or as parental material in breeding programmes of these 28 countries.

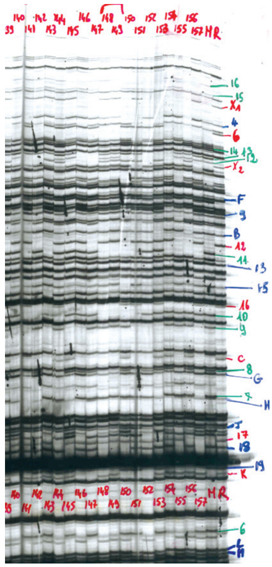

Co 89003

The Institute holds one of the most diverse sugarcane germplasm collections in the world, comprising nearly 4500 accessions. The collection had been characterised for morphological and agronomic traits, disease and pest resistance and tolerance to abiotic factors. Since 1912, Institute had been organising explorations in the distributional areas of *Saccharum* in the country and the activity is still continued. Extensive research on the cytogenetics of *Saccharum* species and interspecific and intergeneric hybrids had been carried out at the Institute. Hybrids involving the different species of *Saccharum* and the related genera *Erianthus, Narenga* and *Sclerostachya* were developed and were cytologically characterised. The Institute also developed unique hybrids of sugarcane with *Imperata*, maize and sorghum.


Co 0238


S. officinarum germplasm

SBI was the first to develop sugarcane tissue culture protocols in India. Several somaclones with modified phenotypes were developed through tissue culture. Co 94012, a somaclone of the popular variety CoC 671, is the first variety developed through tissue culture. This variety, which was released in Maharashtra and Karnataka, has recorded the highest sugar recovery ever. Micro propagation protocol for rapid multiplication of sugarcane varieties was developed by the SBI in the country and this technology was transferred to sugar industry and leading tissue culture labs. Institute has also developed a protocol for medium term *in-vitro* storage of germplasm.


Molecular markers

Molecular studies in sugarcane were initiated for the first time in the country at SBI during 1990s. The genetic diversity and phylogeny of *Saccharum* complex were elucidated using an array of marker systems. Breeding programmes were restructured based on molecular diversity of the parents. Fingerprinting of important varieties has been done. Department of Biotechnology (DBT) has accredited the Institute for virus indexing and genetic fidelity testing of tissue culture plants. Genus and species-specific markers were developed and used for the precise characterisation of interspecific and intergeneric hybrids, which facilitated the monitoring of the wild genome during the introgression with sugarcane. Trait specific markers for red rot resistance, top borer resistance and drought resistance and candidate genes for drought resistance had been identified. Expression profiling of genes involved in sucrose synthesis is in progress. An ubiquitin gene promoter that can express both in dicots and monocots have been isolated from *Porteresia* species and was characterised. Genes contributing to drought tolerance viz., DREB2 and HSP 70 were isolated from the wild relatives of sugarcane and used for transforming sugarcane cultivars. A new vacuole targeting determinant has been isolated and characterised, which will facilitate translocating the recombinant proteins into sugarcane vacuoles. This will have applications in using sugarcane as a platform for molecular farming of high value proteins and manipulating/regulating sucrose metabolism to improve sucrose accumulation.

The Institute was the first to develop sugarcane transgenics in the country. Protocols for biolistic and *Agrobacterium* mediated transformation in sugarcane had been developed. Transgenics with chitinase, 1-3-β glucanase, aprotinin and cry1Ab were developed. While transgenics with aprotinin showed resistance to top borer, transgenics with cry1Ab showed resistance to shoot borer. The first confined field trial of sugarcane transgenics in the country was laid out during January 2011 with the approval by GEAC.

The Institute had developed appropriate technologies for the effective management of the crop under normal and stress situations. Wide row planting was conceived and evaluated to facilitate mechanical operations and the technique is now widely adapted. Effectiveness of bio-fertilizers in reducing the N & P requirement to the extent of 25% was demonstrated. New efficient strains of *Gluconacetobacter* and *Phosphobacteria* were isolated and characterised. A total package for weed management was developed and demonstrated. Experiments on organic cultivation of sugarcane showed that by the third crop cycle, organic cultivation becomes sustainable in terms of productivity and improves soil physical, chemical properties and rhizosphere microbial activities significantly. Studies on micro irrigation showed that over 40% saving in water and nearly 25% saving in N & K fertilisers could be achieved through drip fertigation. Remote sensing and satellite imagery had been used for the first time to delineate Yellow Leaf Disease affected and healthy plantations. Digital soil map of 3 districts have been primed for developing site specific management packages

The management of red rot had been a major focus and the Institute had been largely responsible for the management of the disease in the country through the development of red rot resistant varieties. A Controlled Condition Testing (CCT) procedure was developed to facilitate screening of large number of clones for red rot resistance in a short time. The molecular basis of red rot resistance has been investigated and sixty differentially expressed proteins involved in red rot resistance have been characterised through 2D-GE and MALDI-TOF. The stalk proteome of sugarcane was established as a platform for the study of proteins involved in disease resistance. Three full length genes associated with red rot resistance were sequenced and characterised. Currently transcripts involved in red rot resistance are being identified using subtractive libraries. Complete genome and transcriptome of the fungus have been sequenced through NGS platform. Using molecular tools the causative agent of sugarcane wilt was conclusively established as *Fusarium sacchari*. Complete genomes of five isolates of *Sugarcane yellow leaf virus* (SCYLV) from India were sequenced and they were found to be distinct from the reported YLD genomes. Genome of *Sugarcane bacilliform virus* (SCBV) causing leaf fleck in sugarcane also had been sequenced and was found to be about 7.8 kb in size. Based on the genome sequence information three new species of the virus has been established from the country. Similarly *Sugarcane streak mosaic virus* (SCSMV) was completely sequenced from the country for the first time. An elicitor molecule glycoprotein moiety was isolated from *C. falcatum*, which was found to induce systemic resistance in sugarcane against red rot. Molecular diagnostics have been established for fungal, bacterial, phytoplasmal and viral diseases. A multiplex RT PCR was developed for detecting SCMV, SCSMV and SCYLV simultaneously in a single assay.

Tissue blot was developed to detect RSD bacterium. Virus diagnostic services are being provided to the sugarcane tissue culture industry.

Considerable success had been achieved in the biocontrol of important pests such as the white woolly aphid by using *Dipha aphidivora* and *Encarcia flavoscutellum* and the white flies by using the parasitoid, *Amitusminervae*. The possible use of pheromones in the management of shoot and internode borers had been demonstrated. A *Bt* strain containing a novel cry8 gene which has specific action against the scarabaeid beetles has been isolated from sugarcane soils of Tamil Nadu, a first time report from the country. Significant advancement was accomplished to control the white grub in sugarcane soil by using Entomo Pathogenic Nematodes (EPN) in the tropical regions of the country.

SECTORAL SCENARIO

Sugar Sector in 2050

The projected growth rate of total world consumption of all agricultural products is 1.1% per annum from 2005-07 to 2050. Since, at the world level (but not for individual countries or regions), consumption equals production, this means global production in 2050 should be 60% higher than that of 2005-07.

Consumption has been growing fast in the developing countries, which now account for 73% of world consumption, up from 58% in the early 1980s, including the sugar equivalent of sugar crops used in non-food industrial uses. This is mainly accounted by sugarcane used for ethanol production in Brazil. Consumption in developing countries has been doubled, while that of the developed countries as a whole remained unchanged. An important factor in the stagnation of sugar consumption in the developed countries has been the rapid expansion of corn-based sweeteners in the United States of America, where they now account for over 50% of all caloric sweetener consumption, up from only 13% in 1970.

Table 1 Global trends in sugar consumption

Sugar and sugar crops (white sugar eq.) kg/person/year	1969/ 1971	1979/ 1981	1989/ 1991	2005/ 2007	2030	2050
World	21.2	22.2	21.2	21.2	23.2	24.1
Developing countries	14.5	16.4	17.4	18.3	21.2	23.2
Developed countries	39.5	38.6	34.7	32.8	31.8	31.8
India	7.4	12.3	14.2	18.0	26.0	29.0

World average sugar consumption per capita has been nearly constant over several decades. The fall in sugar consumption in developed countries had been offset by the increased consumption in developing countries. Countries like Brazil, Thailand, Guatemala, and Colombia dominated the export scene, with Brazil being the largest producer and exporter of sugar while several developing countries have become large importers. Besides, policy reforms in the European Union led to declining sugar production necessitating imports during the second half of the 2010s.

The sugar consumption levels are not expected to show any gross change in the coming years. However there will be an increased demand for biofuels which may bring additional focus on sugar crops. Under our "limited biofuels" scenario, use of sugar crops in sugar equivalent will increase from 15% of world sugar output to 27% in 2030 and to 24% in 2050. As a consequence, world sugarcane production should increase (1.3%) faster than world food demand (1.1%) per annum from 2014-15 to 2050.

Indian Scenario

The growth of the sugarcane agriculture in the country had been spectacular. From 1.17 mha in 1930-31, the cane area increased to 5.01 mha by 2013-14; almost a fourfold increase. During this period the productivity went up from 31 t/ha to 68 t/ha, sugarcane production increased from 37 million tonnes to 355 million tonnes and sugar production had gone up from 0.12 million tonnes to 27.9 million tonnes. Sugar recovery also showed an improvement from 9.05% to 10.27%. The number of sugar factories in operation went up from 29 to over 527 at present. The growth in cane and sugar production was contributed by two factors; a fourfold increase in cane area and improvement in productivity by more than 100%. Both these were possible because of the development of new, well adapted varieties along with, efficient crop production and crop protection technologies developed by the ICAR- SBI since 1912.

The demand for sugar, ethanol and power is increasing due to growing population and rising per capita income. The projected requirement of sugar in 2050 is 48 million tonnes (Fig. 1), which is about 100% higher than the present production. To achieve this target, the sugarcane production should be about 550 million tonnes coupled with average

India has harvested a record cane production of 361 Mt from 5 mha with a productivity of 71.7 t/ha in 2011-12 yield of 100 t/ha and 11% sugar recovery from the current 350 million tonnes with 70 t/ha average yield and 10.20% sugar recovery at present. It means the sugarcane production has to be increased by 5 million tonnes annually combined with increment in sugar recovery.

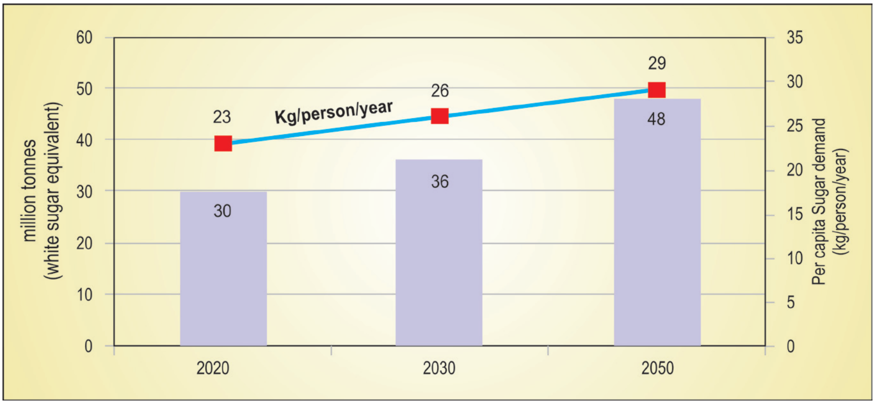


Fig.1 India's future sugar demand (white sugar equivalent)

At present, sugar sector contribute nearly 2200 MW to the power sector through cogeneration against an estimated potential of 5500 MW. Once the cane production is increased, there will be a corresponding increase in the cogeneration potential as well, which is a vital requirement to augment the energy requirement of the country. Thus the sugarcane production has to be significantly increased to meet the growing sugar, energy and power requirements of the country from the existing cane area through improved productivity and sugar recovery since further expansion of cane area is not feasible. On the other hand there are overriding concerns on the static productivity, high cost of cultivation, depletion of natural resources, impact of climate change, etc. which affect the very sustainability of sugarcane agriculture. Improving productivity against these constraints to achieve the projected production targets of 2050 is the real challenge to the sugarcane research and development establishments of the country. This needs special efforts to develop appropriate technologies taking into consideration the demand for the commodities, market trends, likely socio economic situation, the infrastructure and extension machineries available.

The earlier vision documents developed by the Institute largely focussed on sugar sector. But in the present context, where the role of sugarcane as the most important bioenergy crop has assumed equal importance, a revision of the earlier vision approaches has become necessary. Technological advancements in recent years which were not foreseen earlier also demand a revisit to the earlier vision plans. The use of sugarcane as an ideal platform for molecular farming has been demonstrated, which further enhances the importance of the crop on commercial terms. Thus the emerging agro-industrial-technological scenario with respect to the crop warrants strategic planning for 2050, taking into consideration the status of natural resources, productivity limiting factors, availability of inputs and labour, environmental issues and climate change. The SBI Vision 2050 has been prepared in this context to envision and develop effective strategies to meet the sugar and energy needs of the country on a prospective basis.

❑

Challenges

Sugarcane is the basic raw material for sugar production, while molasses and bagasse which are the by-products of sugar industry form the feedstock for ethanol production and cogeneration, respectively. The demand for sugar, ethanol and electricity is increasing due to growing population and rising per capita income. The increased production has to be achieved from the existing cane area through improved productivity and sugar recovery since further expansion in area is not feasible.

Growing Demand for Sugar and Energy

By 2050 the demand for sugar is expected to reach 48 million tonnes as against the current demand of 23 million tonnes, a 97% increase over the current production of 24.4 million tonnes (2013-14). Though 5% ethanol blending with petrol was made mandatory from 2013 in the country, the target could not be achieved due to limited availability of bioethanol, even necessitating imports. National Policy on Biofuel proposes to scale up the blending to 20% by 2017, for which the projected requirement will be about 4400 million litres as against the current production of about 2200 million litres. The estimated ethanol requirement for fuel, potable and industrial use would be 20,000 million litres by 2050. The Indian power sector is the third largest in Asia after China and Japan. The energy demand and supply deficit is about 10% in the country. Promotion of cogeneration and generation of electricity from renewable sources is a declared policy of the GOI. The over 500 sugar mills in the country have a potential to generate 5500 MW of electricity. However the current installed capacity is only 2200 MW. Full capacity realization to the extent of 5500 MW has to be achieved to suitably augment the growing power requirements. This is possible only when the sugar plants operate to their full capacity to generate the required quantity of bagasse. Obviously the cane availability should increase to meet out the capacity utilization of the mills.

Ethanol production and cogeneration are totally dependent on sugar production as the respective feed stocks are generated as by-products during the sugar production. If the sugar production goes up the cogeneration and ethanol production will also correspondingly go up. Enhanced sugarcane production is the utmost necessity not only for the supply of sugar to the growing population but also to supply enough raw materials to the vital sectors of the country. Thus the estimated increase in demand for sugar and ethanol is 100% and 400%, respectively from the current level of production. Scaling up sugarcane production to meet these demands without any increase in cultivated area, is the single most formidable challenge to the sector and requires large investments in research and development.

Production Constraints

In India sugarcane is grown under varied agro-climatic conditions. The crop faces various biotic and abiotic stresses that impact the productivity in a significant way. The major disease affecting the crop is red rot prevalent throughout the country, which has been largely managed through the deployment of resistant varieties. Other major diseases are smut and wilt. However, serious concern is now on yellow leaf disease (YLD) caused by the sugarcane yellow leaf virus, which has spread across the country. As such no resistant varieties are available and the disease needs to be managed through tissue culture-based seed nursery programme combined with virus-indexing as of now. Pests, particularly borer pests continue to be a threat to sugarcane productivity and efforts for management of pests through behavioural, chemical and biological methods have been only partially successful.

Approximately 2.97 lakh ha of cane area is prone to drought, affecting the crop at one or other stage of growth. Drought can bring down the yields by 30-50% and in severe drought situations the loss could be as high as 70%. Floods and waterlogging are serious problems in Eastern UP, Bihar, Odisha, Coastal Andhra Pradesh and parts of Maharashtra. Approximately 2.13 lakh ha of sugarcane area is flood/waterlogging prone in different states. Waterlogging affects all stages of crop growth and can reduce germination, root establishment, tillering and growth resulting in reduced yield. Sugarcane is cultivated in about 7-8 lakh ha under saline and alkaline conditions. Though the crop is moderately tolerant to salinity, the losses are significant. Studies conducted in some of the sugarcane growing countries have shown that the impact of climate change can affect sugarcane production substantially.

Resource Constraints

Continued monocropping of sugarcane without crop rotation and organic recycling for several decades have depleted the soil fertility considerably. Singh (2008) reported that there is an estimated loss of 4.5 to 7.9% in sugarcane yield due to soil degradation in India.

Productivity of the soils has come down due to the degradation of the physical and chemical properties and decline in rhizosphere microbial activities. Decline in soil organic carbon content has been very apparent over the years affecting productivity. Significant reduction in soil organic carbon content following continued sugarcane cultivation had also been reported from Philippines (Alaban *et al.,* 1990) and Brazil (Cerri and Andreux, 1990).

Sugarcane is a water intensive crop, requiring 30-40 irrigations on an average in tropics. Continued mono cropping of sugarcane also has resulted in depletion of water resources at an alarming rate. The water requirement of sugarcane crop is close to 2500 mm in tropics and 1500 in subtropics. Scarce rainfall and depletion of ground water is adversely affecting the cane area and production in serious proportions. The situation is grave enough to warrant moderation of water use of the crop through water use efficient varieties and micro irrigation methods. Sugarcane soils are deficient in some of the macro and micro nutrients, an issue that has not been seriously considered so far. Deficiency in Sulphur, Zinc and Iron is common and can affect the photosynthetic and other biochemical processes contributing to yield.

High Cost of Production

The high cost of cultivation of sugarcane has resulted in reduced profits for the farmers and has led to diversion to other crops bringing down the cane area substantially in certain years. Sugarcane is a labour and input intensive crop which remains in the field for more than a year. The cost of cultivation of sugarcane has gone up significantly due to the increase in cost of labour and inputs. Labour availability for major operations like harvest also has become scarce due to migration of labourers seeking urban employment. Development of varieties and technologies suited for mechanization has become imperative now under the circumstances. The steep rise in cost of production, non-availability of labour in adequate numbers and in time for harvesting and high cost of inputs are eroding the profits, making sugarcane cultivation less sustainable. Sugarcane agriculture can be sustained only if profitability can be ensured through improving productivity thereby reducing cost of cultivation per unit area. This is possible only through mechanization and adoption of other technological interventions in cane agriculture.

Yield Gaps

The experimental maximum yield in sugarcane is 290 t/ha, which is hardly achieved though individual farmers have reported yields close to this. There is a wide gap in productivity between the tropical (82 t/ha) and the subtropical (56 t/ha) regions of the country. Wide gap exists between the potential yield and the yield realized at present in all the states/regions without exception. Bridging this yield gap which ranges from 40% in Haryana to 60% in Maharashtra should be the primary focus for attaining the projected targets.

The emerging crop scenario in sugarcane is a multidimensional one in terms of demand, production constraints, opportunities and technology landscape. To achieve the production targets of 2050, strategic planning becomes absolutely essential taking into consideration the core issues to be addressed, the strengths and weaknesses of the sector, the resources available and to be developed, investments to be made, technological requirements etc. Vision 2050 of SBI is an effort to visualise the emerging scenario and make a quantitative assessment of the sectorial needs and to evolve a strategic plan to achieve the targets in a specified timeframe.

❑

Operating Environment

In India sugarcane is the second most important commercial crop after cotton, contributing 10% of the agricultural GDP per year. The scope and nature of benefits arising from sugarcane cultivation are wide and varied. India is the largest consumer of sugar in the world, the domestic demand is about 23 million tonnes/year. Other benefits from the sugar sector include rural employment generation, export earnings, excise revenue, quasi Foreign Direct Investment (FDI) flows, savings in terms of imports of fossil fuels, employment and revenue generation through the service industry, supplementing electricity generation, moderation of pollution load, carbon sequestration, carbon trading etc. The crop besides providing the food and energy needs of the country also contribute to revenue generation, social development and environmental safety. Because of the multiple benefits from the crop and its wide and varied uses, sugarcane agriculture will remain as a major contributor to the economic growth of the country.

Crop Scenario

The current global sugar production is about 174 million tonnes, nearly 80% of which is contributed by sugarcane. The global demand for sugar at present is close to 168 million tonnes and it is estimated that by 2050 the requirement will go up by over 255 million tonnes. The major sugar producers are Brazil, India, China, Thailand, Indonesia, USA, Mexico and Australia. New sugar Industries are coming up in many African countries like Uganda, Tanzania, Zambia, Nigeria, Ethiopia etc. while sugar production in some of the traditional sugar producing countries like Fiji and Mauritius has declined significantly for various reasons. Massive expansion in cane area is proposed

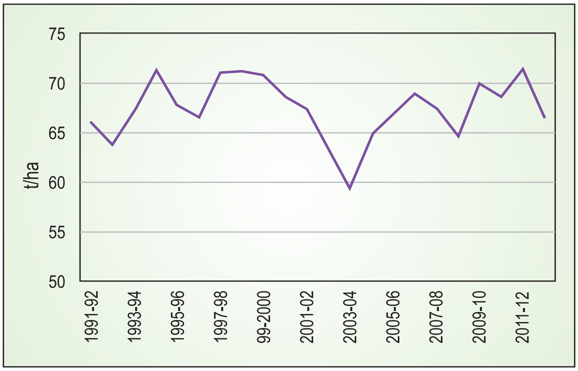


Fig.2 Average yield of sugarcane in India for the past two decades

in Brazil and the cane area is expected to reach 13.9 million ha and sugar production to 45 million tonnes by 2020. Expansion of cane area is also taking place in other South American countries as well. On the whole it is expected that the sugar production will increase substantially in the coming years. India will be in a disadvantageous position since the increased production is from African countries and Brazil, where the cost of sugar production is lower compared to India and we may face stiff competition in international markets. The sugar prices are likely to stabilise at about 40-44 US cents/kg mark in the next 20 years as against the current 32 US cents/kg, in which case the Indian sugar will not be competitive in the international market because of its higher cost of production. Hence our primary concern is to meet the huge domestic demand, being the largest consumer of sugar in the world, rather than aiming at export market.

The scenario with respect to sugarcane in the past 2-3 decades in the country has remained static with respect to production, productivity and sugar recovery. What is of grave concern is that the productivity remained unchanged since 20 years (Fig. 2). Though better varieties and crop production technologies have been developed over the years, their impact has not been duly reflected in the overall productivity. The potential of the existing varieties and technologies remains indisputable, since record yields of 290 t/ha in tropics and 232 t/ha in subtropics have been achieved by innovative farmers using the existing varieties and technologies. Apart from the fact that the technology adoption remains at low levels in major sugarcane growing states, two major factors contributing to the static productivity are the varietal degeneration and decline in soil productivity. Most varieties cultivated today are more than a decade old and being a vegetative propagated crop, varietal degeneration is inevitable which makes the healthy seed programme all the more important in the crop, but not practised rigorously. Likewise, the continued monocropping of sugarcane has resulted in the degradation of the sugarcane soils, particularly in terms of soil organic carbon content, soil physical characteristics and biological properties. The productivity of sugarcane in tropical (82 t/ha) and subtropical (56 t/ha) regions of the country is vastly different. This is due to the prolonged winter in the subtropics which restricts the effective growing period to 9 months unlike in tropics where 12 month growth is possible. The growth and sprouting in winter months is poor in subtropics which affects productivity and imposes serious restrictions on taking second ratoon by farmers. If a quantum jump in productivity has to be achieved, it has to come from the subtropical regions for which varieties and technologies that can improve winter sprouting and growth has to be developed. New diseases and pests are appearing with regularity in the country affecting sugarcane productivity and production significantly. Red rot, the major disease in the country has been managed through the deployment of resistant varieties while solution for new diseases like yellow leaf disease which is causing serious yield losses, the solutions are not in sight. Studies on the likely impact of climate change on sugarcane growth and development, soil physical, chemical and biological properties, carbon sequestration, pest and pathogen dynamics etc. through simulation models and experiments assume importance. Productivity enhancement henceforth is possible only if all the above issues are addressed in a comprehensive manner.

Socio economic situations in the country are bound to impact sugarcane agriculture in the coming years. Tenancy farming is increasing as the new generation farming families are moving out of agriculture. This can result in reduced productivity since investment in terms of land development and agricultural inputs will be minimal under tenancy farming or they prefer to cultivate short duration crops than sugarcane. Large scale migration of agricultural labourers seeking urban employment is causing serious concern as sugarcane agriculture is highly labour intensive. Consequently, the labour availability for critical operations like planting and harvesting has reduced affecting these operations. Labour scarcity has resulted in cost escalation and delayed operations compelling farmers to opt for less labour intensive crops.

Sugarcane and sugar production in India follow a cyclical trend of surplus production leading to fall in sugar prices, delayed payment to farmers, diversion of cane areas to other crops eventually followed by deficit sugar production. Factors like drought, floods, pricing of sugarcane *vis a vis* other crop commodities also contribute to the cyclical nature of sugar production. Sugar was a regulated commodity in the country till recently, which was attributed to have a negative impact on sugar sector. The recent deregulation of the commodity should be viewed as a positive development for the sector in this context and there is distinct possibility of competitive pricing and price stabilisation of sugar which will contribute to overall stabilisation of the sugarcane production as well.

In the energy front, for countries like India which imports 76% of its fossil fuel requirement, enhanced use of ethanol as alternate fuel is imperative. The 5% ethanol blending currently in force has to be increased to at least 20% blending in all states, to save the huge foreign exchange spent on the import of crude oil and to moderate the greenhouse emissions. In India ethanol is solely produced from sugarcane, that too from molasses, as direct use of sugarcane juice for ethanol production is not permitted in the country. There are exciting developments in the area of second generation (lignocellulosic) ethanol and already commercial production of ethanol from lignocellulosic material has commenced in countries like Brazil. It is expected that future ethanol production will be largely from lignocellulosic materials and sugarcane juice will be used for the production of sugar and other high value products.

Butanol is an aliphatic saturated alcohol that can be used as a transportation fuel. Butanol has higher octane value than ethanol, can be used in the existing engines and is non-hygroscopic and non-corrosive to engines. Butanol can be produced from sugarcane juice and molasses using bacterial strains. New strains of *Clostridium bejerinckii* capable of efficient conversion of sugarcane juice and molasses to butanol had been identified and the technology holds promise as an alternate biofuel.

Co-generation is the combined generation of steam and electricity in sugar mills using bagasse as feed stock. Bagasse being a renewable feedstock does not result in the GHG emissions on its combustion and thus generates clean energy. The huge amount of bagasse produced by the sugar industry every season facilitates generation of electricity to meet the operational requirements of the sugar plants, besides exporting surplus power to the grid. The installed capacity for cogeneration in India is 2200 MW while potential is 5500 MW.

Bagasse pulp is an ideal substitute for wood pulp in paper industry. The large scale use of wood pulp for paper manufacture is of grave concern for environmentalists, in view of the dwindling forest resources. This has forced the industry to look for alternative raw material for paper production. Sugarcane bagasse, which has comparable fibre properties has been used for paper manufacture in India and Thailand since long. At present, sugarcane bagasse accounts for nearly 20% of all paper production in India, China and South America. The paper industry utilizes 10% of the world bagasse production. However, the pricing of the different products viz., sugar, electricity and ethanol will decide how and in what proportion the crop is likely to be used for the production of these commodities in the coming years.

Thus the country's sugar, energy and fibre requirements are ever increasing and sugarcane is the only crop that can meet all these requirements. This may require development of superior varieties of sugarcane with high yield and sucrose potential and energy-canes with high biomass potential. The sugarcane and energy-cane production has to be scaled up significantly to meet the growing demand for sugar and ethanol in the country. While sugarcane cultivation will be continued in the traditional areas, the energy plantations will be raised in marginal and wastelands without encroaching the area under conventional crops. The area under sugarcane is not likely to increase from the current 5.2 million ha and the increased production has to be achieved through a vertical increase in productivity for which suitable technological interventions and their timely and effective adoption hold the key.

Technology Landscape

On the technology front the landscape has been fast changing with major discoveries and advancements in biotechnology, next generation sequencing of genome/transcriptome, nanotechnology, geo-spatial technology, ICT etc. which can transform the crop research. The developments in genomics, proteomics and metabolomics have made manipulations of the plant functions at metabolic level possible so as to optimise the productivity and stress tolerance of the crop plants to the desired levels. Genomes of many crop species have been sequenced and many genes contributing to important traits have been identified as also promoters and transcription factors with varied functions. Molecular markers have facilitated genetic diversity analysis, fingerprinting of germplasm and varieties and marker assisted selection to add precision and speed to the plant breeding programmes. The markers have also proved to be a very potential tool for monitoring the introgression of wild genomes for sugarcane improvement. The transgenic technology has provided breakthroughs in crops like cotton, soybean, maize etc. and is the best technological option for trait specific manipulations with the possibility of rectifying specific defects of an otherwise desirable variety with precision. Recently transgenic sugarcane lines were released for commercial cultivation in Indonesia.

Wild species and related genus of sugarcane like *S. spontaneum, Erianthus, Miscanthus* are highly adaptable to various stress and have high biomass. Most can be found growing under drought stress in deserts, waterlogged conditions in marshes and saline conditions near the sea, under a range of temperatures from tropical heat to winter snow, and is found from sea level up to 2700 meter in the Himalayas. These can be a source for a wealth of genes for biotic stress tolerance, abiotic stress resistant, high biomass, high fibre etc. It is worthwhile to exploit these genes for improvement of sugarcane as well as to find an opportunity to commercialise these genes. For this public and/or private partnerships can be exploited to validate application of these genes for other crops as well. Translational research that has commercialisation potential should be taken up by engaging contract research with seed industry to carry out the validation of the genes. This will enable to take forward public funded research to commercialization by creating effective linkages between academia and industry.

Recent report on the development of sugarcane clones with significantly high levels of stored sucrose through the introduction of a sucrose isomerase (SI) gene tailored for vacuole compartmentation holds promise as a strategy for improving sucrose levels. Major focus will be on development of transgenics resistant to weedicide, red rot, yellow leaf disease, drought tolerance, cold tolerance and high sucrose content. Identifying new genes and tissue specific promoters will be the basic requirement for achieving these goals. A substantial research investment is required for the identification and characterization of useful new genes and sequences controlling the expression of important traits in sugarcane. The 'Omic' approach has the potential to reshape sugarcane agriculture to make it more sustainable and competitive. Transgenic technology will be a major driver in productivity enhancement strategies in the coming years despite the current apprehensions on the negative effects of the genetically modified crops. Entomopathogenic symbiotic bacteria *Xenorhabdus* and *Photorhabdus*, engage in a mutualistic association with the entomopathogenic nematodes and are pathogenic toward different insect pests. Broad-spectrum antibiotic, antifungal, antiamoebic, nematicidal, acaricidal, insecticidal and even anticancer and antiulcer properties are produced by symbiotic entomopathogenic bacteria and number of patents has been registered for antibiotic molecules from *Xenorhabdus.*

Another potential area that is emerging is the use of sugarcane as a platform for molecular farming. High biomass potential and multiple ratoonability of sugarcane can be exploited as a biofactory to produce high value molecules like therapeutics, vaccines, vitamins, industrial enzymes etc. on large scale. This is possible by developing technologies for expressing the genes of interest in sugarcane and targeting their storage into the vacuoles which will facilitate easy extraction and purification of the products from the juice.

Nanotechnology has potential applications in enhancing crop productivity in developing countries. In sugarcane, nanotechnology will be useful in the controlled release of agro chemicals and growth promoters to optimise productivity, soil health monitoring through nano-sensors, characterisation of soil minerals, management of soil rhizosphere and effective management of pests and diseases through nano formulations of agrochemicals and bio agents.

It is expected that, in the near future, autonomous vehicles and robotics applications will be at the heart of all precision agriculture applications including sugarcane farming. Agricultural tasks that had been merely mechanised can now be synchronised and automated using simple robotics technology. A wide variety of robotic manipulators are available for industrial operations. Research and development for agricultural operations will centre on the development of sensors and control software. Increased attention to research in basic physical properties of agricultural products will be needed as a basis for sensor development so that sugarcane farms of the future will run on robots.

Numerous aspects of the farm can be automated, which includes automatic sensor based irrigation system, dispersal of plant protection chemicals and secure temperature controlled enclosures for different farm products. Automatic soil water sensor-based irrigation preferably using solar pumps will maintain a desired soil water range in the root zone that is optimal for plant growth. With the rapid advancements in electronics, computers and computing technologies, the farm automation can proficiently moderate the amount of manual labour and make farming easier and faster, leading to more growth in sugarcane farming system.

ICT has a major role in technology dissemination. A comprehensive database on various aspects of crop requirements across the agro-climatic zones supported by suitable web enabled, interactive, multilingual Sugarcane Decision Support System will serve as an effective platform for technology transfer. Innovative approaches to harness the potentialities of ICT such as voice messages in local languages and mobile telephony (SMS) can reduce transaction costs and bridge time and space barriers in information delivery.

Commercialisation of Technologies

Until now sugarcane research had been largely carried out by public funded institutions and the varieties and technologies developed are under public domain. There are changes taking place globally in terms of investments in sugarcane research as there is more private participation now, particularly with new opportunities emerging in energy and molecular farming sectors using sugarcane as a platform. In India also private investments in sugarcane research is taking place with multinational companies evincing keen interest in investing in sugarcane research. With the new initiative of this Institute on development of hybrid varieties using inbreds, apomixis and haploidy, sugarcane cultivation through true seed will be a reality. This success would attract investments by private seed companies in sugarcane research. Consequently, new norms are emerging with sugarcane genes, promoters, varieties and processes being IPR protected by public and private institutions. The technology developments could be hereinafter driven by the commercialization potential as well, though public institutions will continue to focus primarily on farmers' interest. There is an urgent need to protect the technologies developed by the public funded institutions to remain competitive and self-sustaining. The rewards and economic gains from the technologies developed needs to reach the institutions and research personnel who had developed them and ultimately benefit the farming community at large.

The operating environment that governs sugarcane research leading to 2050 is thus conditioned by various factors including the demand for the different commodities derived from the crop, global market trends, socio economic situations, production constraints, environmental issues, new opportunities in terms of product diversification, emerging technology landscape, etc. The research needs have to be prioritized keeping in view the interests of the main stakeholders of the sector viz., the sugarcane farmer, the industry and the consumer, for the sustained growth of the sector to ensure sugar and energy security of the country.

❑

Opportunities

The demand for sugar has increased significantly in the past 25 years particularly in developing countries. The per capita consumption in developed countries, which at present stands at 42 kg/person/year, is not likely to increase further. But in the developing countries, particularly the Afro-Asian countries, the consumption is expected to go up from the present 19 kg/person/year to 24 kg/person/year in the next 40 years. The overall growth rate in consumption is expected to be 1.25% per annum and by 2050 the global sugar requirement will be 255 million tonnes. Developing and underdeveloped countries need to increase their production by one and half times to meet the domestic requirements of their increasing population. In India, the sugar sector is constrained by the non availability of land for area expansion. The domestic demand for sugar is pegged at 48 million tonnes by 2050, from the current 23 million tonnes. Though this is a stiff challenge, it also provides the opportunity for the sector to improve productivity and production.

Twenty per cent of the sugarcane produced is used for jaggery production. The per capita consumption of jaggery which at present is 5 kg per annum, has shown a declining trend over the years. But still there are established markets for this commodity particularly in certain traditional areas. The market for organic jaggery is likely to go up as a health food. Similarly, there is an emerging market for packaged sugarcane juice. These products will provide additional opportunities for the sugarcane farmer.

World energy consumption has been growing exponentially over the years that the expenditure on oil during this decade will be almost equal to the expenditure on oil during the previous 100 years. The dwindling nature of the fossil fuels, financial strain on non-oil producing countries and grave environmental concerns demand the use of alternate fuels. The Brazilian experience has shown that ethanol is one of the environmentally safest and economically viable alternatives to fossil fuels. The combined demand for ethanol in India for industrial uses and 20% blending with petrol across the country is estimated to be 20,000 million litres by 2050 as against the present production of 2200 million litres. This is to be considered as an opportunity for the sugar industry to diversify the product line for additional revenue generation. The production of cellulosic ethanol using sugarcane residues, for which technologies are under development, will be a breakthrough for the low cost production of ethanol, without diverting the cane juice for the purpose. The global availability of bagasse is estimated to be about 425 million tonnes annually. This huge biomass can be an important feed stock for the production of bioethanol. This is particularly important for countries like India, where scope for increasing the production of ethanol from molasses or sugarcane juice is very limited. However, the limitation so far had been the lack of cost effective technologies to convert bagasse to ethanol. Use of butanol to replace ethanol as an alternate fuel in automobile sector will be the likely development to take place in near future. Butanol can be produced from sugarcane juice using suitable microbial strains. Butanol being a high octane fuel with better calorific value and less hygroscopic in nature compared to ethanol, could be the next generation biofuel to be seriously considered.

Co-generation by the sugar mills has an estimated potential of 5500 MW in the country. Bagasse being a renewable feedstock does not result in the GHG emissions on its combustion and thus generates clean energy. The huge amount of bagasse produced by the sugar industry every season facilitates generation of electricity to meet the operational requirements of the sugar plants, besides exporting surplus power to the grid. At present, the total electricity produced through cogeneration is only 2200 MW, but is likely to go up with more sugar factories establishing cogeneration facilities. The use of bagasse for paper manufacture is increasing due to concern for saving forests and nearly 20% of all paper produced in India, China and South America is from sugarcane bagasse.

Apart from being the most important and commonly used sweetener, sugar is also a raw material for the production of a host of industrial chemicals and nearly 10,000 technically feasible products have been developed from sucrose at laboratory and pilot plant scale. Some of the important products with industrial applications derived from sugar are acetic acid, citric acid, citrates, lactic acid, lactates, glutamate, sysine, xylitol, acetone/butanol, 2,3 butanediol and Polyhydroxybutyrate (PHB).

The opportunity for using sugarcane as a platform for molecular farming is a serious proposition, considering the high biomass potential and multi ratoonability of the crop. Sugarcane had already been engineered to produce high value molecules including therapeutics, enzymes, vaccines, bioplastics, etc.

Sugar industry being rural based, provide opportunity for further diversification in milk processing and diary technology. Many problems (low cane yield and sugar recovery, shortage of pulses, oil seeds etc.)

related to sugarcane agriculture can be solved by popularising autumn planting with intercrops like pulses, oilseeds, vegetables etc. in subtropical India. For achieving this target, the sugar industry have to help the farmers by ensuring the marketing of intercrops.

Thus the crop offers a wide range of options to be exploited suitably in the coming 35 years. For this the 'sugar factories' have to transform themselves into 'Sugarcane Processing Complexes' producing a wide range of products apart from sugar. Cane agriculture also needs to diversify as per the industry needs into 'sugarcane plantations', 'energy plantations' and 'sugarcane biofarms', growing sugarcane for different purposes. In the research front also there are effective tools available now that were not available previously. The modern tools of omics, bioinformatics and transgene technology can redefine the varietal development process and tailor varieties as per needs. The geospatial technology, nanotechnology and ICT will be potential tools for developing effective crop production and crop protection technologies.

❑

Goals and Targets

The necessity to grow enough food, feed, fuel and fibres to meet requirements of the ever-increasing population has put tremendous pressure on natural resources and their management. There is degradation of resource-base in the form of large scale soil and water erosion in the hill and plateau areas, appearance of wide-scale secondary salinization and water logging in the irrigated and flood-affected areas, deterioration in water quality, diminishing forest cover and inaccessibility to the costly inputs in agriculture.

Targets set for 2050 have been framed to ensure sustainable and stable sugarcane production in the country, taking into consideration the likely demand for sugar and other products, the emerging crop scenario with respect to domestic and global markets, sustainability of the crop in terms of economic returns, growing concerns on depletion of natural resources, impacts of climate change, new opportunities likely to arise and the advancements in frontier areas of science. The effort will be to integrate the conventional and newer technologies in a mutually complementing way leading to technological innovations that will drive the sustained growth in the sector.

The major goals set for 2050 are:

- Sustainable sugarcane production with improved productivity to ensure sugar and energy security in the country.
- To develop alternate uses of sugarcane in terms of energy, fuel and as a platform for molecular farming.
- To make sugarcane agriculture climate resilient and resource efficient.

The targeted action plan for achieving these goals is:

- Development of new improved varieties suited for different agro-climatic conditions of the country.
- Mechanisation and improving water use efficiency.
- Conservation of natural resources to ensure sustainability of sugarcane cultivation.
- Development of suitable crop production technologies to maximise the productivity under varied agro-climatic conditions.
- Development of crop protection technologies to minimise crop losses due to diseases, pests and nematodes.

- Developing technologies for alternate uses of sugarcane.
- Assessing and mitigating the climate change impacts.
- Capacity building in key areas including biotechnology, nanotechnology, geospatial technology and ICT.
- Technology assessment and transfer through effective communication system.
- Ex ante and post impact assessment of technologies and economic assessment of the sugarcane production trends and market access.

❑

Way Forward

ICAR-SBI had contributed immensely in fulfilling the research needs of the sugarcane crop during last more than 102 years of its existence through timely varietal and technological interventions in the country. The 'Co' and 'Co-allied' varieties, being cultivated in the country, have played a significant role in sustaining and expanding the cane area and sugar production. Looking ahead, a long term planning of research agenda for the next 40 years has inherent risks, since precisely visualising the likely future scenarios with respect to the crop and the direction in which scientific developments are likely to progress is difficult. However, it is still possible to develop a strategic framework for research on a time scale to achieve the projected targets based on the likely demand for various commodities, potential threats to productivity, socio-economic-environmental concerns, resources available, emerging technology landscape and new opportunities. This will serve as the basic frame work for setting the research agenda, subject to on course correction as the situation warrants. Vision 2050 of ICAR-SBI has been prepared as a roadmap for achieving the production targets taking into consideration the above facts. The approach is theme based, on a problem solving mode through multidisciplinary approach. The projected requirement of sugar during different years in the country is given in Table 2.

Table 2 Projections on area, cane yield, sugarcane production, sugar recovery and sugar demand in the country

Year	Sugarcane area (mha)	Yield (t/ha)	Sugarcane production (Mt)	Drawl (%)	Sugarcane to be crushed (Mt)	Recovery (%)	Sugar produced (Mt)	Sugar demand (Mt)
2020	5.0	75	375	0.75	281	10.25	28.8	28.0
2030	5.5	80	440	0.80	352	10.75	37.8	36.5
2040	5.5	90	495	0.80	396	11.20	44.4	43.9
2050	5.5	100	550	0.80	440	11.50	50.6	47.9

mha – million hectares; Mt – million tonnes

These projected demands of sugar in the country are proposed to be achieved from about 5.5 mha, as the area under sugarcane is not expected to increase beyond this in the country. This roadmap has been prepared on the assumption that contribution of crop improvement and crop production technologies in enhancing the productivity would be 60% and 20%, respectively. Rest of 20% contribution towards achieving the targets would be in the form of preventing losses due to crop protection efforts. An objective long term roadmap, of research agenda up to 2050, would be a valuable guiding document to the researchers towards meeting the future projections of sugar and related products. An effort has been made to draw this roadmap of multidisciplinary research activities on a time scale to achieve the projected targets.

2015-2020

(Targeted cane yield: 75 t/ha and sugar recovery: 10.25%)

Crop Improvement

- Rejuvenation of seed and establishment of seed nurseries (meristem culture-virus free TC plants-aerated steam therapy- 3 tier seed nurseries-enforcing seed standards)
- Release three varieties for tropics with 100 t/ha average cane yield and 11.5% recovery and three varieties for subtropics with 85 t/ha and 10.5% recovery (selection of superior clones and faster multiplication for popularising)
- Varietal scheduling in each sugar factory area (prominent variety not more than 60%, other 4-5 varieties 5-10% area each, early varieties, short duration varieties, high fibre, high yield and late maturing varieties for co-generation)
- Developing ten clones with 110 t/ha average cane yield and 12% recovery for tropics and ten clones with 90 t/ha and 11.0% recovery for subtropics (utilising diverse parents, pre-breeding material from interspecific/intergeneric hybrids, trait specific genetic stocks)
- Genetic stocks for high yield traits and abiotic stress tolerance (from commercial hybrids and from pre-breeding material from interspecific /intergeneric hybrids)
- Studies on trait specific genes for yield, quality, biotic stresses, abiotic stresses, flowering, etc. (gene identification, cloning, sequencing and characterisation from commercial varieties and from wild germplasm)
- Genes/gene constructs for drought, YLD resistance
- Develop transgenics for abiotic stresses (drought, salinity, cold, high temperature, water logging)
- Identifying parental clones for hybrid seed production (homozygous lines by inbreeding/doubled haploids, apomixis)

Crop production

- Developing technologies for soil health management through integrated nutrient supply system, organic recycling, improved fertilizer use efficiency and enhanced soil carbon stock and exploiting the information technology for their deployment
- Technologies to achieve higher water and nutrient productivities-automated drip irrigation and improved fertigation schedules, chemigation of eco-friendly and selective herbicides, fungicides and insecticides, soil moisture conservation and organic recycling
- Exploiting the eco-friendly and selective molecules for the management of problematic weeds in sugarcane
- Developing comprehensive technology package for mechanized sugarcane cultivation through settling transplantation, ratoon management, machineries to suite local sites in different agro-ecological zones
- Technology refinement for abiotic stress management through soil amelioration, exploitation of genetic resources and crop management practices. Improving the knowledgebase on the mechanisms of biotic and abiotic stress tolerance in sugarcane
- Sugarcane rhizosphere engineering: studying the basis of genotype variations, stress response and other changes in the rhizosphere in response to environmental changes

Crop protection

- Adoption of healthy crop management programme [reduction in yield loss by 3%]
- Evaluation and identification of varieties for red rot, smut and YLD resistance to increase yield in endemic areas. Managing fungal diseases and insect pests through new generation chemicals and new delivery systems [reduction in yield loss by 2%]
- Reducing losses caused by insects, diseases, nematodes and non insect pests by adopting integrated management involving novel biological approaches, infochemicals, EPNs etc. Nano-based field diagnosis of sugarcane diseases [reduction in yield loss by 3%]

2020-2030

(Targeted cane yield: 80 t/ha and sugar recovery: 10.75%)

Crop improvement

- Rejuvenation of seed and establishment of seed nurseries

- Release five varieties for tropics with 110 t/ha average cane yield and 12.0% recovery and three varieties for subtropics with 90 t/ha and 11.0% recovery
- Varietal scheduling in each sugar factory area with less than 50% area for the major variety and 4-5 varieties with 10-15% area each having different maturity/stress tolerance
- Developing 10 clones with 115 t/ha average cane yield and 12% recovery for tropics and 10 clones with 95 t/ha and 11.0% recovery for subtropics
- Genetic stocks for high yield traits, biotic and abiotic stress tolerance
- Identification of trait specific genes for yield, quality, biotic stresses, abiotic stresses, flowering, etc.
- Developing transgenics for drought, YLD resistance of popular varieties
- Introduction of transgenics for abiotic stresses for commercial cultivation
- Identifying true seed hybrids for commercial cultivation

Crop production

- Implementation of IT based soil health management system, water productivity, soil moisture conservation, residue recycling and soil carbon sequestration technologies
- Development of site and genotype specific nutrient-manure-agro chemical-microbial mixtures
- Development of automated drip irrigation technologies for efficient delivery of custom made and programmed fertilizers, eco-friendly agrochemicals including selective herbicides, fungicides and insecticides, rhizosphere modifiers, biotic and abiotic stress management molecules.
- Deployment and demonstration of improved machineries for sugarcane cultivation in farmer's fields; basic studies on automation of sugarcane cultivation
- Developing and refining comprehensive technology packages for sugarcane cultivation from seedling and true seeds - pre-nurtured seedlings and seeds
- Eco-friendly weed management packages - development and deployment
- Commercialization of beneficial molecules from sugarcane juice: Anti-oxidants, bioavailable elements and minerals, vitamins etc.

Crop protection

- Adoption of healthy crop management programme including nano-based field diagnosis of sugarcane diseases [reduction in yield loss by 3%]
- Evaluation and identification of varieties for red rot, smut and YLD resistance to increase yield in endemic areas. Managing fungal diseases and insect pests through new generation chemicals and new delivery systems. Nano-based field diagnosis of sugarcane diseases [reduction in yield loss by 2%]
- Identification, characterization and utilization of novel genes for varietal development by transgenic approaches for built-in resistance to insects (novel toxin genes) and pathogens (pathogen derived/ disease resistance genes). Priming with SAR, ISR inducing agents, endophytes etc. supported by a nano-based delivery system for disease/pest management [reduction in yield loss by 2%]
- Reducing losses caused by insects, diseases and nematodes by adopting integrated management involving novel biological approaches, infochemicals, EPNs etc. Nano-based field diagnosis of sugarcane diseases [reduction in yield loss by 2%]

2030-2040

(Targeted cane yield: 90 t/ha and sugar recovery: 11.2%)

Crop improvement

- Commercial production of true seeds
- Release five varieties for tropics with 115 t/ha average cane yield and 12.0% recovery and three varieties for subtropics with 95 t/ha and 11.0% recovery
- Developing ten clones with 120 t/ha average cane yield and 12% recovery for tropics and ten clones with 95 t/ha and 11.0% recovery for subtropics
- Develop breeding stocks utilizing trait specific genes for yield, quality, biotic stresses, abiotic stresses, flowering, etc.
- Popularising transgenics for biotic and abiotic stresses and non-flowering in the best variety for commercial cultivation
- Introduction of true seed hybrids for commercial cultivation and enterprises for commercial true seed production
- Identification and utilization of apomictic genes

Crop production

- Development of comprehensive ecosystem management technologies bundled for site specific and yield target based sugarcane cultivation and on site delivery through IT enabled tools
- Deployment of systematic and automated inputs delivery through drip irrigation system for nutrients, weeds, insect pests and pathogen management, rhizosphere modification and biotic and abiotic stress management - exploitation of artificial intelligence in diagnosis, decision making and technology delivery
- Development of need based machineries for sugarcane agriculture, unaided automatic diagnostic tools for nutrient and stress symptoms
- Development of fortified true seeds with all input requirements

Crop protection

- Adoption of healthy crop management programme including nano-based field diagnosis of sugarcane diseases [reduction in yield loss by 6%]
- Evaluation and identification of varieties resistant to red rot, smut, YLD and emerging diseases/insect pests to increase yield in endemic areas. Transgenic varieties with in-built resistance to insect pests and pathogens [reduction in yield loss by 3%]
- Use of remote sensing satellite imageries to assess pest and disease damages of the crop at national level and appropriate management strategies. Reducing losses caused by insects, diseases and nematodes by adopting integrated management involving novel biological approaches, efficient delivery of plant protection chemicals, infochemicals, EPN, transgenics, etc. [reduction in yield loss by 3%]

2040-2050

(Targeted cane yield: 100 t/ha and sugar recovery: 11.5%)

Crop improvement

- Release five varieties for tropics with 120 t/ha average cane yield and 12.0% recovery and three varieties for subtropics with 100 t/ha and 11.5% recovery
- Commercial cultivation of transgenics with high cane yield of 120 t/ha and 12% recovery for tropics and 100 t/ha and 11.5% recovery for subtropics with multiple genes for biotic and abiotic stress tolerance, non flowering, high quality, etc.

- Developing ten clones with 125 t/ha average cane yield and 12.5% recovery for tropics and ten clones with 100 t/ha and 11.0% recovery for subtropics
- Develop breeding stocks utilizing trait specific genes for yield, quality, biotic stresses, abiotic stresses, flowering, etc.
- True seed hybrids for commercial cultivation in at least 20% of cane area
- Utilization of apomictic genes for commercial sugarcane production

Crop production

- Comprehensive technology bundles for ecosystem specific target oriented sugarcane agriculture
- Soil ecosystem modifiers to suit specific genotypes developed for sugar, bio-energy, fibre, bio-molecules etc.
- Artificial intelligence based remote diagnostics for nutrient and environmental stress identification, remediation using eco-friendly formulations and positive crop physiology and biochemistry modifiers, eco-friendly agro-chemicals for weed, pest and disease management through drip irrigation system
- Automated irrigation system with high water productivity, need based delivery and online quality remediation
- Fortified true seeds with complete nutrients and agro-chemicals for achieving genotype and environment limited potential yield
- Bio-engineered microbes for nutrient fixation, rhizosphere modification, bio-energy production from the products and byproducts of sugarcane

Crop protection

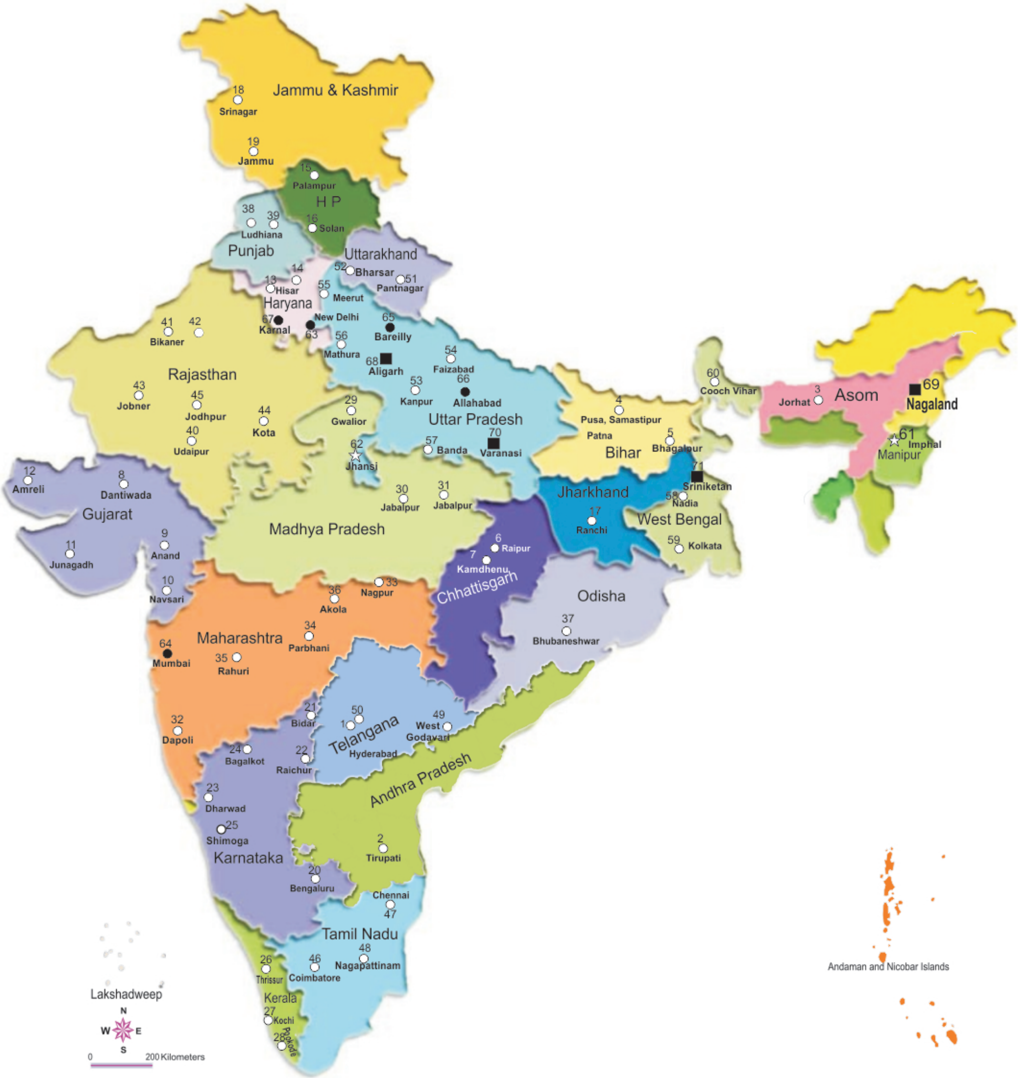
- Adoption of healthy crop management programme including nano-based field diagnosis of sugarcane diseases [reduction in yield loss by 6%]
- Evaluation and identification of varieties resistant to red rot, smut, YLD, emerging diseases/insect pests to increase yield in endemic areas. Transgenic varieties with in-built resistance to insect pests and pathogens [reduction in yield loss by 3%]
- Use of remote sensing satellite imageries to assess pest and disease damage to the crop at national level and appropriate management strategies. Reducing losses caused by insects, diseases and nematodes by adopting integrated management involving novel biological approaches, efficient delivery of plant protection chemicals, infochemicals, EPN, transgenics etc. [reduction in yield loss by 3%]

NOTES

Laser typeset at M/s Royal Offset Printers, A-89/1, Naraina Industrial Area, Phase-I, New Delhi 110 028.
Printed at Thannambikkai Printers, Coimbatore - 41. Mobile: 98650 10414.

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Agricultural Universities



LEGENDS

State Agricultural Universities	○
Central Universities with Agricultural faculties	■
Central Agricultural Universities	☆
Deemed Universities	●

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

Agrisearch with a human touch