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

Agrisearch with a human touch

Vision
2050

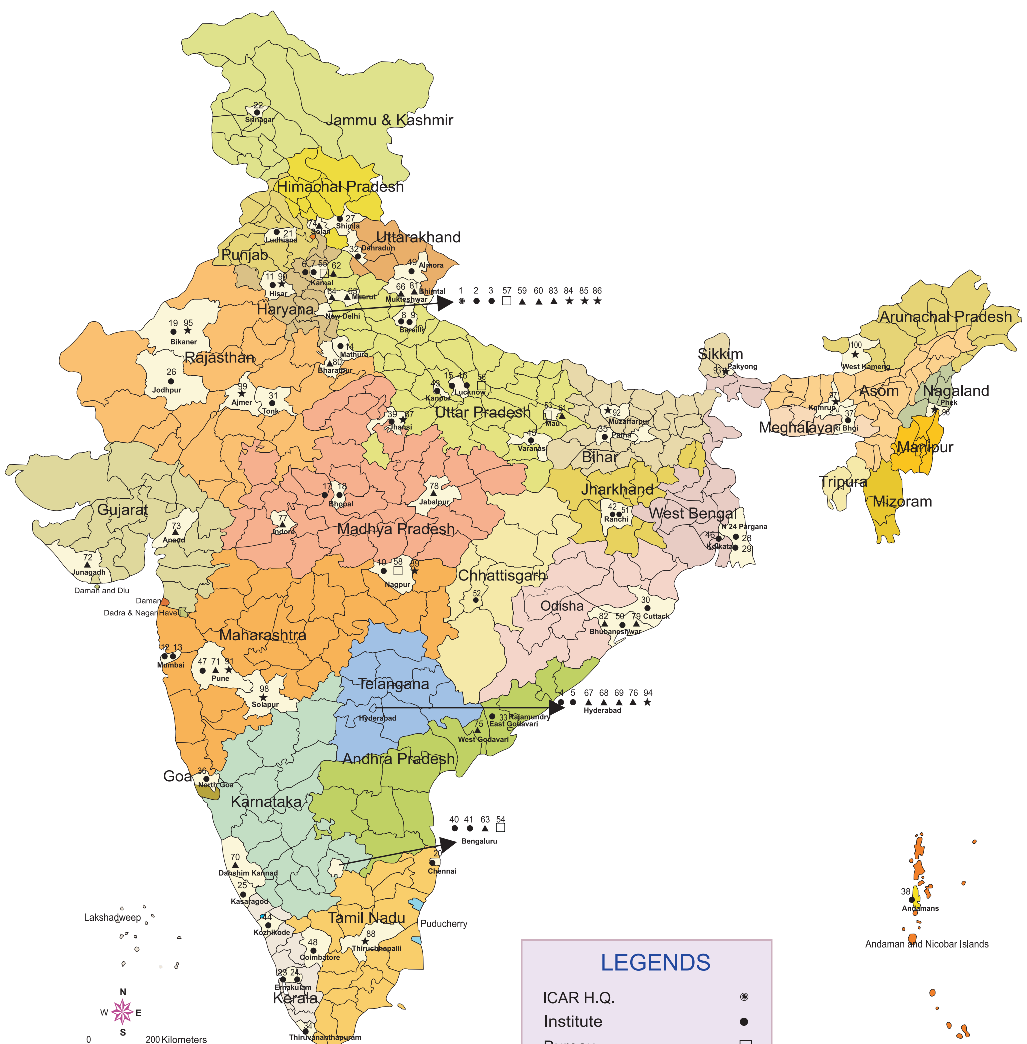
भाकृअनुप
ICAR

Directorate of Soybean Research

Indian Council of Agricultural Research

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Institutes, Bureaux, Directorates and National Research Centres



LEGENDS

ICAR H.Q.	◉
Institute	●
Bureaux	□
Project Directorate	▲
National Research Centre	★

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

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Agricultural Universities

LEGENDS

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

Vision 2050

भाकृअनुप
ICAR

Directorate of Soybean Research
(Indian Council of Agricultural Research)
Khandwa Road,
Indore 452 001 (M.P.)

www.dsrindore.org

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)

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-Directorate of Soybean Research (DSR), Indore 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 advent of commercial exploitation of soybean in India is nearly four decades old. In this short spell of time, the crop has shown unparallel growth in area and production. The area under soybean has increased from a meager 0.03 m ha in 1970 to 12.2 million ha in 2013-14. Mean national productivity has increased from 0.43 t/ha in 1970 to 1.35 t/ha in the year 2012-13. The compound growth rate of area and production for soybean in India has been 11.2 and 12.8 per cent per annum from 1976-77 to 2012-13. Soybean has established itself as a major *kharif* crop in the rainfed agro-ecosystem of central and peninsular India. Introduction of soybean in these areas has led to a shift in the cropping system from rainy season fallow followed by post-rainy season wheat or chickpea (fallow-wheat/chickpea) to soybean followed by wheat or chickpea (soybean-wheat/chickpea) system. This has resulted in an enhancement in the cropping intensity and resultant increase in the profitability per unit land area.

In India, soybean will continue to remain a major rainfed oilseed crop. The simulation studies and on farm demonstrations have clearly indicated that with current varieties, the rainfed potential of soybean in India is about 2.1 t/ha against the national average productivity of just 1.2 t/ha. Hence, large yield gaps exist between the potential and the actual yields harvested by the farmers. Narrowing of this yield gap can lead to doubling of soybean production and productivity. National Agricultural Research System has so far been successful in matching the research demands of agrarian and industrial community step by step. However, to meet the growing demands by 2050 in terms of edible oil, food uses, meal for animal feed and various other industrial uses of soybean, we need to explore the untapped research areas, usher in new research methodologies and make efforts that have been unprecedented so far. The present endeavor "Vision 2050" is one such effort to have long term strategy in place so as to tackle the challenges posed by changing demographics, climate, agrarian and industrial requirements. We are thankful to all the officials of Indian Council of Agricultural Research (ICAR) and in particular to Dr. S. Ayyappan, Secretary (DARE) & Director General (ICAR), Dr. J.S. Sandhu, Deputy Director General (Crop Science) and Dr. B.B. Singh (Assistant Director General, Oilseeds and Pulses) for their valuable suggestions in finalizing this

Document. I place on record my appreciation for Drs. S.M. Husain, Dinesh K. Agarwal, S.D. Billore, Purushottam Sharma and S.V. Ramesh for their sincere and painstaking efforts in bringing this immensely important exercise into this shape.

V. S. Bhatia
Director
DSR, Indore

Contents

Context

As the cliché goes that necessity is the mother of invention, research since time immemorial has been driven by the needs of the time. Story of human endeavour in field of science and technology has largely been the relentless struggle for the need of survival against ever changing scenario of its existential requirements and extremities with innovation being the only tool available to wage this war. There are changing needs that can be met with mid-term corrections and reorientations but then there are requirements that need foresightedness and corroborating timely preparations to be able to tackle those. Agricultural technologies fall to one such category that has long gestation period and hence, demand clarity of vision to be able to gauge the looming threats and opportunities. Among major agricultural commodities, soybean [*Glycine max* (L.) Merrill] has a prominent place as the world's most important seed legume, which contributes 26.7% to the global vegetable oil production, about two thirds of the world's protein concentrate for livestock feeding and is also a valuable ingredient in formulated feeds for poultry and fish. Due to its unique chemical composition (20% oil and 40% protein), the crop has potential to mitigate rampant protein energy malnutrition in India, in particular, and developing world in general. Besides, a number of nutraceutical and functional compounds such as isoflavones, tocopherol and lecithin make it an ideal health food.

Table 1. World Area, Production and Productivity of Soybean

Year	Particulars	Country					
		USA	Brazil	Argentina	China	India	World
2011-12	Area (m ha)	29.86	23.97	18.75	7.89	10.18	103.81
	Production (m t)	84.19	74.82	48.88	14.49	12.21	261.94
	Yield (kg/ha)	2820	3121	2607	1836	1200	2523
2012-13	Area (m ha)	30.80	24.98	17.58	6.75	10.84	104.92
	Production (m t)	82.05	65.85	40.10	13.05	14.67	241.14
	Yield (kg/ha)	2664	2637	2281	1933	1353	2298
2013-14	Area (m ha)	30.70	27.86	19.42	6.60	12.2	111.27
	Production (m t)	89.48	81.70	49.31	12.50	11.95	276.41
	Yield (kg/ha)	2914	2932	2539	1894	979	2484

Source: FAO

In India soybean has established itself as a major rainy season crop in the rainfed agro-ecosystem of central and peninsular India. Introduction of soybean in these areas has led to a shift in the cropping system and has resulted in an enhancement in the cropping intensity and thereby increase in the profitability per unit land area. The advent of commercial exploitation of soybean in India is nearly four decades old. In this short spell of time, the crop has shown unparallel growth in area and production (Fig. 1). Area under soybean has increased from a meager 0.03 m ha in 1970 to 12.2 million ha in 2013-14. The production has increased from 0.01 million tonnes in 1970-71 to 14.67 million tonnes in 2012-13. The mean national productivity has increased from 0.43 t/ha in 1970-71 to 1.35 t/ha in 2012-13. Not keeping pace with the growth in area and production, the growth in productivity of soybean has been slow with large year-to-year variations (Fig. 1). The large variation in productivity in soybean across years is mainly associated with rainfed nature of the crop and hence, its dependence on the rainfall. Still the decade-wise analysis of growth in yield indicates a linear increase in productivity of soybean in India (Fig. 2). The major soybean growing states are Madhya Pradesh (6.38 m ha), Maharashtra (3.92 m ha), Rajasthan (1.18 m ha), Andhra Pradesh (0.25 m ha) and Karnataka (0.23 m ha). The crop is fast spreading in southern states such as Andhra Pradesh and Karnataka. Soybean could play a significant role

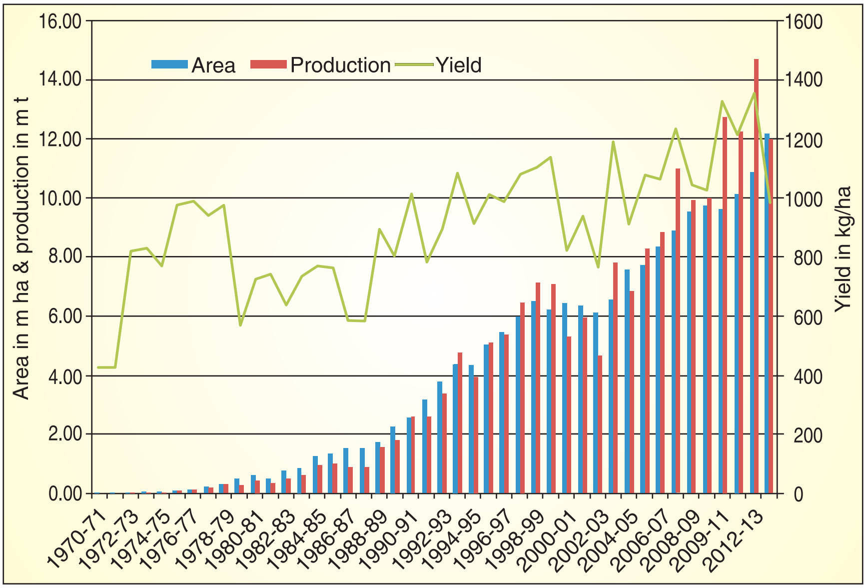


Fig. 1 Growth of soybean in India since the commercial cultivation began in 1970s.

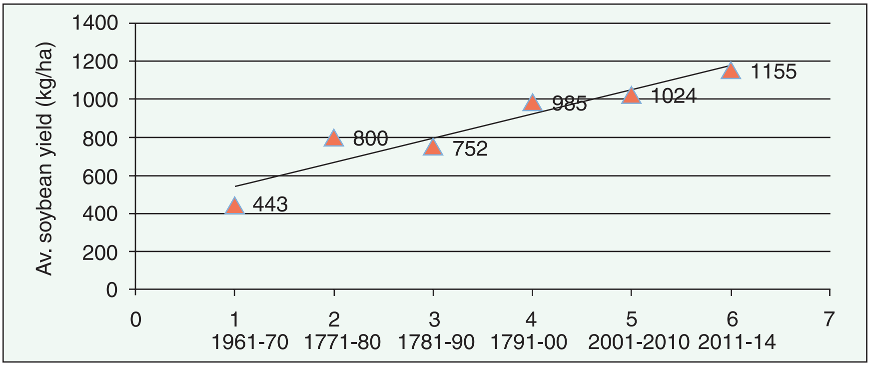


Fig. 2 Decade-wise soybean productivity in India

in northern states such as Punjab which is looking for diversification from rice-wheat to other cropping systems. The crop earns valuable foreign exchange (Rs.138205.7 millions in 2013-14) by exporting soya meal. At present soybean contributes about 42% and 26% to the total oilseeds and edible oil production of the country.

India is the fourth largest vegetable oil economy in the world. After cereals, oilseeds are the second largest agricultural commodity, accounting for the 14% of the gross cropped area in the country. However, the country is meeting its edible oil demand by importing about 50% of its requirement. The per capita consumption of the vegetable oil is increasing very rapidly due to increase in population and improved economic status of the consumers. The demand has increased to about 14 kg/year compared to 4 kg/year in 1961 and the projected demand for the year 2020 and 2050 is 15.33 and 16.97 kg/year respectively. To meet this demand, the country will require nearly 23.81 and 39.16 million tons of edible oil. In this scenario, soybean has played and will continue to play pivotal role in future. A four fold increase in production (from current 12.94 m t to 46.8 m t) due to one and half fold increase in area and more than two fold increase in productivity is projected for soybean by 2050 (Table 2).

The food derived from soybeans is generally considered to provide both specific and general health benefits. Being a cheaper source of high

Table 2. Projected soybean area, production and yield in India

Crop	Base (TE 2013-14)	2020	2030	2040	2050
Area (Million ha)	11.05	11.35	15.71	17.71	18.35
Production (Million tonnes)	12.94	16.8	27.5	37.2	46.8
Yield (qt/ha)	11.7	14.8	17.5	21.0	25.5

quality protein, the crop has potential to alleviate large scale protein malnutrition prevalent in poor sections of the society in the country. Inclusion of the high quality soybean protein in daily diet will provide the nutritional security to Indian masses. Already the Government of India as well as private sector has taken initiatives to increase the food use of soybean in the country.

The ICAR started All India Coordinated Research Project on Soybean (AICRPS) in 1967 and established National Research centre for Soybean (NRCS) in 1987 at Indore in Central India. The NRCS was further upgraded to Directorate of Soybean Research (DSR) during the XI plan. The AICRPS is an integral part of the ICAR-DSR with 8 main, 14 sub and 16 need based centres, spread across the nation. The system is well equipped with human resource, equipments and infrastructure to conduct quality research.

The ICAR-DSR right from its inception has been involved in promotion of soybean in the country. The research efforts made by ICAR-DSR in terms of new soybean varieties, improved production and protection technologies and dissemination of these technologies to farmers has led to a giant leap in area, production and productivity of soybean in India. To develop improved varieties possessing superior agronomic traits, resistance/tolerance to biotic and abiotic stresses and improved quality traits, ICAR-DSR has consolidated soybean germplasm resources. Presently, 4248 germplasm accessions are being maintained that also includes wild relatives of the cultigen. Majority of these genetic resources have been evaluated and characterized for different traits and are being actively shared with soybean breeders across the country. So far 100 improved soybean varieties possessing various traits such as high yield potential, earliness, tolerance to biotic and abiotic stresses, and food grade qualities have been developed and released for cultivation in different agro-ecological zones of India. Through these varieties, the initial problems such as poor seed germination, pod shattering and tolerance to some of the major diseases such as YMV in soybean have been addressed to a great extent.

In the five years of XI plan (2007-2012) the crop area, production and productivity has increased by 21, 38 and 14%, respectively. Consequently, the contribution of soybean to total major nine oilseeds production in the country has increased from 36.4% to 41% by the end of XI plan. During this period, 15 new improved soybean varieties were identified and released for cultivation to the farmers. A number of new sources for traits such as drought tolerance, photoperiod insensitivity, resistant to diseases such as rust and YMV, resistant to insects such as girdle beetle and defoliators, and food uses such as vegetable types, high oil content, high oleic acid content, low lipoxygenase content and null Kunitz Trypsin inhibitor were identified. To enhance the efficiency of breeding programmes using molecular tools, the QTLs for high seed longevity and markers for YMV resistance genes were identified. Matching crop phenology with the available resources in terms of soil moisture etc. is essential for harnessing the optimum productivity for a rainfed crop. Therefore, optimum phenology for harnessing maximum yield of rainfed soybean in central India was worked out. During this plan period a number of improved crop production and protection technologies were developed, validated and demonstrated to the farmers. For better nutrients availability, tolerance to abiotic stresses, and improve productivity, the efficient *in situ* production technologies for arbuscular mycorrhizal fungi (AMF) has been standardized. A number of microorganisms such as efficient and heat tolerant rhizobia and other PGPR with growth promoting properties have been identified. For efficient agronomic management and improving resource use efficiency in soybean cultivation, a number of farm implements have been developed and commercialized. Notable among them are the farm machines needed for planting of soybean on improved land configurations (BBF planter and FIRBS) for *in situ* moisture conservation and drainage of excess water under high rainfall conditions are gaining popularity among the farmers. Using simulation techniques, irrigated and rainfed yield potential and yield gaps of soybean across India have been worked out. Taking into account the climate change concerns, the impact of projected future climate in terms of increased CO_2 levels, temperature and change in rainfall, has been quantified. It is projected that soybean productivity at national level may increase by about 8 per cent from the current level under

Major highlights of XI plan

- Area, production and productivity of soybean increased by 21, 38 and 14%, respectively
- Fifteen new improved soybean varieties identified and released for cultivation
- Number of new sources for traits such as drought tolerance, photoperiod insensitivity, diseases and insects resistance and food uses identified
- QTLs for high seed longevity and markers for YMV resistance genes identified
- A number of improved production and protection technologies developed, validated and demonstrated to farmers
- Using crop growth models irrigated and rainfed yield potential and yield gaps of soybean across India were worked out
- Number of farm equipments developed and commercialized

the climate scenario of 2050. However, large spatial variability across soybean growing regions with increase in productivity in Central India and a decline in Southern India has been projected.

To meet manifold increase in the demand of soybean for edible oil, animal feed and direct consumption as a food, on one hand, and climate change and new emerging challenges posed on the other hand, the ICAR-DSR would continue to strive for increasing productivity, enhancing input use efficiency, reducing cost and post-harvest losses, minimizing risks and improving quality of end use commodity through conventional techniques as well as new science and tools. ICAR-DSR and AICRPS centres pursuing soybean research in India are well equipped with human resources and infrastructure for conducting quality research. Through their unified efforts and with support from soybean industry, non-governmental organizations and farmers, role of soybean in oil economy of the country can further be improved. The advancement in research component culminating to improved varieties and agro-ecological zone specific production technologies has been a driving force in motivating the other components of production system to function in harmony leading to unparallel growth of the crop and elevated socio-economic status of small and marginal farmers.

It has been proven implicitly or explicitly that most of the measured agricultural productivity growth is attributable to research and development (R&D). Increasingly, questions arise as to how much productivity growth might be attributable to factors other than organized R&D such as evolving weather patterns, institutional changes, or size of economies associated with changing structure of agriculture. In many cases it is likely that organized research has been the primary contributor to the observed productivity growth. Research takes a long time to affect production, and then it affects production for a long time. Keeping in mind the long gestation period of agricultural technologies compounded by dynamic nature of external factors such as evolving climate, demographics and market considerations, it is of paramount importance to have the country's long term planning in place to meet emerging exigencies.

❑

Challenges

While it is impossible to paint a scenario in exactitude that is still thirty five years away, considering plurality of the governing factors, one may attempt to have a broad outline of needs and challenges that lie ahead. There are a number of factors that would affect the general scenario of Indian agriculture and soybean in particular by 2050 and warrant a relook on part of policy planners and researchers to spell out a contingent planning.

General challenges

India would be the most populous nation on the earth by 2045 where every 5th global citizen would have an Indian citizenship. At the same time the country would probably be at the threshold of being a near developed nation with largest middle class population on the planet wielding enormous purchasing power like never experienced before. Both these combined would mean a humungous demand for food that could only be met by doubling the current food supplies. As the economic prosperity would enhance among ever growing masses, there would probably be a distinct shift in existing food habits moving from current high mass low energy to high mass high energy foods, that would reflect in increased burden on supply of high energy food items such as edible oil and fats.

Climate Change: Potential Impacts on Indian Agriculture

- Productivity of most cereals would decrease due to increase in temperature, CO_2 and decrease in water availability.
- A projected loss of 10-40% in crop production by 2100.
- 1°C increase in temperature may reduce yields of major food crops by 3-7%. Much greater losses at higher temperatures with longer duration. Greater loss expected in rabi.
- Length of growing period in rainfed areas is likely to reduce, especially in peninsular regions.
- Increase in CO_2 to 550 ppm increases yields of rice, wheat, legumes and oilseeds by 10-20%.

Source: B. Venkateshwarlu (CRIDA)

By 2050 both industry and agricultural economies would probably converge with each other. Agriculture would substantiate a large portion of energy requirement of industrial world and apart from filling empty bellies it would have the added responsibility of keeping the furnaces alive. Owing to intense industrialization, man-power availability for agriculture would further downsize severely, leading to highly mechanized farming. With small size of average land holding in India it would alter the traditional agricultural practices in the country like never seen before.

Climate change effects, resulting from higher levels of atmospheric CO_2 and temperatures, deviations in total precipitations & its distribution and seasonal shifts would alter the agricultural scenario world over by paradigm shifts in mega-production zones. There could be heavy setbacks to food production across large parts of the globe that would need to be compensated by the new mega-production zones. India would probably have the added responsibility of feeding large section of global humanity.

Specific Challenges to Soybean as a Crop

As far as specific challenges to soybean crop are concerned, the heavy demand for edible oil and fats would put enormous strain on soybean as a most important oilseed crop in India. Soybean researchers would have to be ready with technologies/ varieties having potential of a quantum increase in yield to two and a half time than its current level. This Herculean task would require matching efforts by farmers also. There would be a war cry for utilizing immensely valuable soya-protein for finding a way into human diet for ensuring nutritional security for large masses. Continued efforts on the food uses of soybean will become a necessity. Changed consumer preferences with enhanced affluence would also require a lot of innovation to develop novel culinary applications of soya food. Also, till date soya-economy has largely been dependent upon overseas demand for soy meal, by 2050, soya-economy has to have its strong base in domestic market so as to minimize any external vulnerability.

Changed climatic conditions by 2050 may lead to novel production areas and strategies. Soybean breeders, crop husbandry and protection scientists have to be ready with necessary realignments in various technological components to be able to harness the changed scenario for their benefit. The technologies would require an inbuilt capability to make crop extremely resilient to weather and climatic fluctuations and extremities. Soybean germplasm curators would have the task cutout for them to have their entire collection sequenced to effectively tag the useful SNPs available across their collections. Soybean breeders would have the challenge of introgressing valuable traits from secondary and tertiary gene pools by utilizing widely available and established tools of modern biotechnology. Genetically modified soybean would possibly become a norm for effective biotic stress management (weeds, insect pests and diseases) and would widely be acceptable across globe thus making it imperative for India also to have GM soybean in the country. Researchers would have to be ready with production technologies compatible with GM soybean.

In all probability, 2050 would warrant the new agronomy for soybean keeping in mind the vastly changed availability profile of land, nutrient, water, varieties and labour. Efforts are needed to study them in detail and develop compatible interventions. Soybean agronomical practice would require designer PGP microbes to support plant growth in terms of enhanced availability of nitrogen, phosphorus, zinc and other micro-nutrients and probably would also be helpful in carbon sequestration as well as in making the crop more drought resilient. Extremely reduced labour availability to agricultural sector would necessitate agricultural engineers to come out with machinery for highly mechanized soybean cultivation.

The insect pests and diseases minor at present and/or altogether new biotic stresses may pose serious threat in next thirty five years requiring plant protection scientists to be on high alert for any such emergence and be ready with effective remedial interventions.

Global competitiveness is going to play a critical role in further expansion of crop in the country. The growth in inputs use is increasing for cultivation of soybean, leading to low or stagnant total factor productivity. This poses a challenge before scientists to develop production technologies for higher productivity with reduced input utilization.

❑

Operating Environment

There would probably be a sea change in operating environment for crop in terms of competition for resources and research requirements based on enhanced demand for production and productivity, climate change, changed consumer preferences, mechanization *etc.* and in terms of available research tools such as genomics, phenomics, transcriptomics, nano technology and ICT (Information & Communication Technology). These are summarized below:

Projected increase in population would put tremendous stress for increasing production and productivity of agricultural commodity. Additionally, upsurge in economic status would result in increased demand for food items particularly fats and oils. Increase in population buttressed by increasing affluence would lead to faster urbanization which would mean reduction in availability of arable land. Precious inputs for agriculture like water and soil nutrient would also show declining trend of availability owing to intensive exploitation. Also the novel food and industrial application are likely to drive the agriculture enterprises.

Change in climatic patterns would compel major realignments in existing cropping pattern and systems. The projected change in climate may lead to emergence of new insect pests and diseases which assume menacing proportion and large segment of agricultural area could be under abiotic stresses. An increase in the number of outbreaks of a wider variety of insects, nematodes and pathogens and increased damage potential of existing and invasive pests and diseases is anticipated. Disruption of the temporal and geographical synchronization of pests and beneficial insects may increase risks of pest outbreaks. Increased use of pesticides could lead to development of resistance against chemicals and microbial insecticides resulting in pest outbreaks and negative impact

Frontier Areas of Research for 2050

- Search for new genes
- Climate change
- Biodiversity
- Genomics and phenomics
- Molecular breeding
- High value and secondary agriculture
- Disease diagnostics
- Conservation agriculture
- Nano technology
- Converting waste to wealth
- Multi-purpose crops: grain, sucrose, fodder, fuel

on environment and agricultural economy. It would warrant working in Public-Private-Partnership (PPP) mode with insecticide industry in collaborative projects to make use of available infrastructure at each end.

Development in genomics would hasten up improvement of the targeted traits. Gene tagging and sequencing would greatly facilitate trait discovery in the germplasm and its rapid delivery in suitable agronomic backgrounds. Genetically modified soybean would be the standard norm for weed and insect management and production of industrially suited designer oil.

Advent of next generation sequencing (NGS) and variety of inexpensive sequencing platforms in vogue would enable rapid sequencing of all available germplasm accessions and resequencing of indigenous cultivars. This sequencing aided "omics" approach would generate wealth of genomics and transcriptomics information that in turn would help in identifying agronomically superior genes, resistant gene analogues (RGA) conferring resistance to pest and diseases, genotyping valuable SNPs, characterizing *cis*-acting elements, and non-coding RNAs (ncRNAs) in soybean genotypes. The information would accelerate genetic improvement of soybean with the combined efforts of molecular breeding tools and transgenic development programmes.

In view of the depletion of nutrient status of soils there is an urgent need to achieve greater nutrient use efficiency and optimize the use of chemical fertilizers. Designer microbes would facilitate enhanced availability of bound soil nutrients such as phosphorus, zinc and other micro nutrients. Advancement in nano technology would benefit agriculture in better molecule delivery of externally aided nutrients and plant protection chemicals.

Decline in availability of agricultural labour would lead to intensive mechanized farming. Better penetration of information and communication technology would completely revolutionize the transfer of technology and this would be greatly augmented by accurate short and medium term weather forecasts and insect pests and disease forewarning.

❑

Opportunities

As there would be unprecedented challenges in multitude to face thirty five years down the timeline, there would be plethora of unforeseen technological advances that would be unleashed. Soybean research and development would greatly benefit from advancement in field of germplasm management, crop breeding, biotechnology, crop physiology, soil & nutrient management, plant protection, nano technology and information & communication technology. The concerted strategies would be needed to attend the goals of enhanced soybean production and productivity along with the associated mission objectives of bolstering Indian farmers' economic status and eradication of maladies of protein-energy malnutrition.

These strategies include impact assessment and development of management strategies for current and future climate variability in soybean in terms of responsive varieties, production and protection technologies including suitable farm machinery and quality traits matching future consumer preferences. The focus will also be on the enhancement of genetic resources and evaluation for desirable traits to combat the emerging problems. The identified genetic sources will be used for crop improvement using functional genomics, MAS, transgenic and allele mining approaches. Harnessing hybrid vigour and accumulation of yield related QTLs to overcome genetic yield barriers will provide opportunities to enhance the genetic yield potential of soybean.

Increased food and industrial uses of soybean would provide opportunities to develop specialty soybeans. The increasing consumer preference for organic food products would necessitate development of sustainable organic farming in specific areas/regions. This will also cater to the needs of premium local and foreign markets.

The new technological advancement would help in better management of biotic and abiotic stress scenarios and facilitate the knowledge transfer amidst clientele through aggressive and efficient extension tools. The immense opportunities are anticipated to promote and develop technologies for soybean based secondary agriculture. To meet the future research challenges, there will be greater opportunities for institutional capacity building through intensive HRD.

❑

Goals and Targets

Stern challenges that lie ahead could successfully be tackled by matching technological advancement only if the goals/targets are known and well defined. Based on the challenges, goals to be achieved by 2050 are detailed below.

The genetic resources of soybean have been extensively augmented, evaluated and documented so far. To address research requirements of the future, ICAR-DSR will facilitate use and consolidation of available genetic resources by (i) enrichment of soybean genetic resources through import/exchange of trait specific soybean accessions from large sources like USDA (USA), AVRDC (Taiwan) and China; (ii) molecular characterization and gene flagging through functional genomics, proteomics, phenomics, etc.; (iii) broadening the genetic base through genetic enhancement and pre-breeding, and (iv) TILLING and utilization of chip technology. Looking at the future climate change, the breeding programmes would also focus on development of varieties with tolerance to high temperature conditions and better response to elevated levels of CO_2. Early maturity is an important breeding objective, first to fit it in the multi crop situation and secondly to escape moisture stress in late season. For two to three fold increase in present productivity by 2050, besides the conventional breeding approaches, new tools such as allele mining, Marker Assisted Selection (MAS), functional genomics, genetic engineering and exploiting hybrid vigour will be pursued. The use of biotechnological approaches in crop improvement with activities like development of mapping populations, tagging and pyramiding useful genes and marker assisted selection in breeding of varieties with higher yield and insulation against major stresses will get a major impetus. This will also include development of efficient regeneration and transformation protocol to pave the way for transgenic development.

Despite its rich nutritional profile, use of soybean in food has been limited because of its beany flavour (lipoxygenases) and presence of anti-nutritional factors like trypsin inhibitor. Therefore, breeding for genotypes with improved quality traits such as low lipoxygenases, null KTI, low phytate along with high oil and oleic acid content would be an important objective in future.

Looking at the increased and changed insect-pest scenario in future, it will be imperative to develop forecasting models for major diseases and insect-pests of soybean involving epidemiological studies and threshold levels. It will also require identification, molecular characterization and preservation of biodiversity in pathogen, insects and other microbes. Overall goal will be effective management of biotic (insect-pests, diseases and weeds) and abiotic (nutrients, moisture and thermal) stresses based on integrated approach.

For sustainable production of soybean through conservation agriculture, integration of approaches on microbial community, nutrient dynamics, soil quality in different cropping systems will be taken up. The target will also be on developing farming system models for different categories of farmers.

❑

Strategies for 2050 and Outcome

To achieve the set targets/ goals of two to three fold enhancement in the soybean productivity by 2050, the strategies with their expected outcome are detailed below.

> **Main Targets of Vision 2050**
>
> - A two to three folds increase in land productivity
> - A two folds increase in water productivity
> - Doubling of energy use efficiency
> - Three to four folds increase in labour productivity
>   - About half through labour
>   - Capital substitution
> - Low carbon emission

High throughput SNP analysis will be taken up for characterization of germplasm and development of trait linked haplotypes using association mapping. This will also include enhancement of trait specific germplasm by utilizing haplotype signatures. Allele mining for the identification and characterization of rare alleles present in soybean germplasm will enhance the availability of desirable alternative alleles. These strategies will lead to discovery of novel genes for soybean improvement.

Advanced gene modification technologies will be employed to associate candidate genes with a discrete phenotype. Appropriate protocols for gene stacking will be developed in soybean based upon computer modeling. Gene sets will be developed for modeling specific plant architecture to suit various growing conditions and their utilization using genetic modification or gene stacking.

Using genomics, phenomics, bioinformatics and other biotechnological approaches, new genotypes will be developed with resistance to biotic and abiotic stresses, and higher yield. Identification of novel genes, promoters and other regulatory elements which are responsible for tolerance to drought, high temperature and important biotic stresses will help in developing climate-resilient varieties.

Breaking seasonal boundaries and developing soybean varieties for all seasons with broader adaptation to sowing dates (long juvenile soybean varieties) will help in increasing the adaptability of soybean varieties. This will be achieved by identification of new soybean maturity genes and their best combinations for different locations and subsequent efforts like targeted breeding for photoperiodic responses (Photosensitivity and long juvenility). Genotypes with broader adaptation to sowing dates would preclude the need for changing the variety when rains are delayed and would stabilize the productivity. Soybean varieties for different season would help the crop to fit in cropping sequences of various regions.

By 2050, farmer's requirement would be to produce more with less water. A second green revolution using drought tolerant varieties of soybean would be sustainable. The strategies to achieve this would be to develop drought tolerant soybean varieties with sustained nitrogen fixing ability under drought stress and delayed wilting.

Today, as much as 40 % of irrigated area suffers from excess soil moisture conditions in India which may become worse by 2050. Generally, the high yielding varieties of soybean have shown low levels of resistance to water logging. Except, JS 97-52 there is no variety tolerant to water logged conditions. Understanding the genetic mechanism of water logging tolerance and combination of conventional and molecular breeding methods would help in overcoming this problem.

Efforts will be made to develop genotypes with increased digestible sugars and balanced amino acids profile for providing better food and feed. There will be emphasis on developing varieties with higher oil content to meet the growing demand, as well as developing genotypes with specific oil and meal traits for niche markets. This will require functional characterization of the oil biosynthesis pathway genes to design an array of soybean genotypes with different oil quality.

Nano technology holds a great promise of controlled release of chemicals and fertilizers which will be employed for improved nutrient utilization and enhanced plant growth. The technology can help in enhancing the availability of nutrients by reducing the particle size. Low grade rock phosphates can easily be made as a source of P to the plant when they are converted to nano-size (<100 nm). Similarly, deposits of glauconite/waste mica can be successfully utilized as source of K to plants by converting them to nano-size particles. Natural mineral deposits like dolomite and magnetite (as source of Ca & Mg), pyrite (as source of Fe and S), can be made useful for agricultural use with a reduced cost and without impairing the environment.

Phosphorus sources would be exhausted in the coming 60-70 years. Identification of soybean genotypes with improved phosphorus uptake is required. This will be achieved by deciphering the mechanisms of improved phosphorus uptake and their genetic controls leading to identification and cloning of genes involved. Phosphorus uptake efficient varieties would be capable of taking phosphorus from its fixed form available in soil.

Also, mycorrhizal hyphae have been found to carry phosphate, nitrogen and zinc ions to the plants and therefore may take part in biosynthesis of different inorganic nano-particles. The conditions required to control the size/shape and stability of particles need to be studied. The applications of these biosynthesized nano-particles in a wide spectrum of potential areas can be exploited such as biosensors for enhanced P and Zn uptake in plants. Also higher soybean yields at reduced doses of phosphatic fertilizers would be achieved by molecular characterization of functional P-transporter genes and by transformation of plants with AMF phosphate transporter genes. Bio-fortification of soybean for improved Zn and Fe content in seeds would be achieved through development of bio-inoculants consortia using nano technology.

Way Forward

- Bridging technology gap between researchers and farmers
- Bringing India at par with world soybean productivity
- Harness other sciences (space, engg., bio science)
- Move gradually from conventional R&D management and governance model – to alternative models
- Develop strategic partnership and alliances - Other Public, Private, International
- Balancing futuristic research and problem solving research
- Identify game changers for long run soybean research
- Bring disciplinary integration and institutional consolidation necessary for scientific and basic research.
- User's perspective: demand driven and responsive research, delivery to end users
- Prioritization: Varieties, technologies, region, secondary uses
- Impact assessment: Social relevance, public image, accountability.
- Bring system's perspective to research and draw from specialized knowledge

The current primary production zone of soybean which is in central India is increasingly facing stresses caused due to natural and anthropogenic factors. Plant-associated microbes would play an important role in conferring resistance to abiotic stresses. These organisms could include rhizoplane and endophytic bacteria and symbiotic fungi and operate through a variety of mechanisms like triggering osmotic response and induction of novel genes expression in plants. The microbial inoculation to alleviate stresses in plants would be a more cost effective and environmental friendly option by 2050.

Efficient surveillance of insect, nematode and disease incidences using remote-sensing and GIS will be required. This would help in timely control of these biotic menaces, and ultimately leading to reduced losses and increased farm income. Promotion of Green Plant Protection

Technologies employing microbial control (bacteria, viruses, fungi, PGPR, nematodes, etc) and genetic resistance will help in sustainable soybean production and reduce dependence on hazardous chemicals.

Production of quality soybean seed and maintenance of its quality (in terms of high germination and vigour) during storage is still a challenge and projected climate change may further accentuate this problem. It is expected that by 2050 nano technology will play an important role in seed invigoration leading to better germination and field emergence of soybean seeds under congenial as well as adverse conditions of low and excess soil moisture. Efforts will also be on to develop low cost eco-friendly seed storage technique which will help in protecting valuable seeds from incidence of insect and pathogen and high humidity.

❑

Future Road Map

For making soybean climate resilient and to move it from a commodity to value-added crop, it is necessary to develop the infrastructure and capability to handle different research and developmental requirements of soybean. This will include ways to improve crop husbandry, to measure the traits of interest accurately and consistently, and to deliver and finally to store, ship, and process the value-added crop in reliable and efficient manner. To build new systems or modify existing systems to meet these needs will require substantial investments. It is a major challenge to move from research/development of varieties with improved traits into production and converting them into harbinger of means of survival and prosperity in the future. To overcome these challenges, flagship programmes aimed at analyzing the impact of current and future climate variability, developing suitable adaptation strategies to overcome the adverse effects on soybean, developing soybean varieties and production technologies suited to current and future climate scenarios and developing soybean varieties for food uses has been targeted in XII plan. Under the flagship programme, infrastructure required to achieve the set goals has been approved. To achieve the goals and targets of vision 2050, ICAR-DSR is also actively participating in ICAR research platforms such as i) Agro-Biodiversity platform to characterize, evaluate and utilize the genetic resources of soybean, ii) Climate resilient agriculture platform for assessing the impacts of future projected climate and development of adoption strategies to overcome the adverse impact on soybean, and iii) Seed platform for development of technologies for production, management and improvement of seed quality in soybean.

❑

NOTES

NOTES

NOTES

Laser typeset at M/s Print-O-World, 2568, Shadipur, New Delhi 110008 and printed at M/s Royal Offset Printers, A-89/1, Naraina Industrial Area, Phase-I, New Delhi 110 028.