Agricultural Economics Research Review
Vol. 26(No.1) January-June 2013 pp 1-20

Presidential Address

Indian Agricultural R&D: An Introspection and Way Forward[1]

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1. Agricultural R&D for Socio-economic Development

Agricultural science has always played a critical role in economic progress in both developed and developing economies. Through agricultural R&D, welfare improvement has been realized in the form of lower food prices to domestic population, improved nutrition, expansion in rural employment, agricultural exports and enhanced level of foreign exchange, competitiveness of agricultural commodities in the world markets and strong growth linkages with rest of the economy. During the green revolution period, adoption of new technologies has helped to improve the income distribution across income classes (Hazell and Ramasamy, 1991). Ever since at least the time of Ricardo, the theology of development has emphasized that agricultural progress contributes to the support of greater productivity throughout the economy. Kuznets summarizes these contributions as 'market contribution' and 'factor contribution' (Kuznets, 1965).

Applications of S&T to modernization of agriculture turned to be visible since 17th century and first occurred in Europe. It may be noted that Royal Agricultural Society of England, founded during 1790s in UK, paved the way for growth of experimental farming. In the 1860s, about the same time as Gregory Mendel discovered the cross breeding of different strains of pea plants and predicted the traits of the offspring. After his work was rediscovered with some time lag, the science of plant breeding took off. Almost 150 years have passed since US public-sector agricultural research and development (R&D) began in earnest with the establishment of the US Department of Agriculture. Subsequently, in US agriculture, Public and Private agricultural R&D played a major role in bringing about changes.

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India also saw the beginning of scientific farming with the establishment of Department of Agriculture in each Indian province in 1880 under the British rule. Next step was to establish Imperial Agricultural Research Institute to foster agricultural research and education and decentralization of agricultural developmental activities to the Provincial Governments in response to Montague–Chelmsford Reform (1919). This led to co-evolution of research and education (Swaminathan and Ravi, 2007). When the country got independence, in the efforts to develop country's agriculture, promotion of agricultural R&D was considered as the most important one. The agricultural review team chaired by Dr M.W. Parker of USDA (1963) suggested far-reaching changes in organization and management of agricultural research in the country. The research centres across the country came under the one roof of Indian Council of Agricultural Research. Corresponding changes occurred at the state level with the transfer of research and education to State Agricultural Universities (SAUs). All these efforts culminated in the development of agriculture as a modern sector along with rest of the economy and agriculture emerged as key sector.

[1] Based on Presidential Address delivered on 9 October, 2012 at the 20th Annual Conference of Agricultural Economics Research Association (India) held at Indian Agricultural Research Institute, New Delhi.

2. Challenges in Indian Agriculture

During 12th Plan, it is aimed to have 9 per cent growth of the economy as a whole, which warrants 4 per cent growth in agriculture. An average household still spending half of its expenditure on food and food products (NSSO Survey, 2009-10), meeting the food demand will be formidable, given the scenario that consumption is likely to be more diversified as, at present, cereals account for only 15 per cent the total consumption expenditure. However, the demand for cereals used in animal feed is accelerating. The key to ensuring long-run food security lies in targeting cereals productivity to increase significantly faster than the growth in population. Having begun 'Bringing Green Revolution in Eastern India', upcoming challenges at the national level remain to be: need for more investment in infrastructure, soil nutrient management in the situation of exponential growth in fertilizer subsidy, significant gap between the varieties released by the public sector institutions and the varieties adopted by the farmers, private sector research and seed industry focusing only on varieties and hybrids with massive markets, rain-fed crops getting lesser research attention, and misgivings about transgenic food crops, under funding of agricultural research, cultivars with stress tolerance to climate change, under performance of extension agencies, frequent failure in timely availability of quality seeds, inadequate fodder availability and poor access to animal healthcare to support dairy industry, lesser success in linking small producers with markets and urgent need for improving the productivity of common pool resources (Planning Commission , GOI, 2011).

Further, prices received by the farmers for their products have failed to keep pace with costs or the general price level and, as a consequence, profitability declines unviable proposition. On the supply side, no dramatic technological breakthrough has happened since green revolution period. With limited success in increasing water-use efficiency in irrigated agriculture, rain-fed area of 200 million hectares with largest concentration of poverty, remained way behind in terms of technology adoption (CRIDA, 2007). India's smallholder farmers are much less empowered to access crucial production resources despite many programs aimed at them (National Commission on Farmers, 2005). The natural resource base of Indian agriculture is becoming increasingly limited. Analysts have expressed concern for a secular decline in public investment in agriculture. Private investment in agriculture is also increasing only in small increments. Despite a number of reforms introduced in agricultural marketing, the marketing efficiency has not significantly improved.

Technological change has been the main engine of agricultural growth in India. Strong empirical evidence provides support that high levels of R&D lead to high productivity and therefore improved economic performance. R&D was found to translate into significant rates of return in primary and service sectors, registering as high as 60 per cent (Cororaton, 1998). The Total Factor Productivity (TFP) growth, which was the main driving force for the overall growth of agricultural output during 1980s in India, has started slowing down in recent years. Various authors have estimated growth in TFP of agriculture in India (Evensen *et al*., 1999; Kumar *et al*., 2004; Bhushan, 2005). The growth rates range from 0.9 to 4.0. In few cases, there are negative growths also. The slowdown in TFP is a reflection of poor contribution by agricultural research and almost a near nonperformance by public extension system. Indian policymakers have created one of the largest agricultural R&D systems in the world. The knowledge and technologies generated by investment in R&D was primarily responsible for the green revolution and achieving food security for the huge population. Despite success of green revolution, India still houses one-fourth of theworld's hungry and poor and 40 per cent of the world's malnourished children and women (NAAS, 2009). The NSSO-2005 survey revealed that 40 per cent of the farmers would relinquish farming if provided alternate options. This is mainly because the economic viability of farming is threatened.

Thus, Indian agriculture which has shown to the world that food security to a huge population can be achieved through scientific agriculture and its proper implementation (in the form of green revolution) during 1960s through 1980s, has shown a fatigue and struggles to manage the new dynamics. Overall, it has under-performed during the past two decades and is not prepared adequately to address the existing, emerging and future needs of the people and the economy.

3. Challenges in Agricultural R&D

(A) Public Sector R&D

Besides ICAR and SAUs as the primary units of public research system, private sector research, ICFRE, organizations such as CSIR, UGC, and BARC, IITs, IIMs, and agriculture-related faculties and departments in general universities do take up agricultural research on specific issues. These other institutions spend about 7 per cent public spending on agricultural R&D (Beintema, 2008). Private sector research is playing a greater role in the development of agribusiness[2]. International Agricultural Research Centres (IARCs), particularly ICRISAT, has contributed significantly to R&D on rain-fed farming in India. CGIAR centres, viz., IRRI, IFPRI, CIMMYT and other international centres have strong linkages with Indian agricultural research system.

Indian NARS has a huge scientific workforce of 21869 scientists (Jha and Kumar, 2006) and ranks fourth in the world in terms of total investments in public R&D, following USA, Japan and China (Beintema, 2008). ICAR has many scientific achievements in terms of evolving modern crop varieties/hybrids and a number of crop management technologies. One can ask whether agricultural research has been successful over the past century. The positive impact of research can be seen from the decline in the real prices of foodgrains since green revolution. Many studies have established the high rates of return to agricultural research investment in India (Alston *et al*., 2000; Ramasamy, 1997). An examination of facts and figures clearly establishes that agricultural research during the second half the 20th century has been remarkably successful. The contributions of state agricultural universities in the form of trained manpower and generation of new technologies, as partners of NARS are well recognized. In spite of notable achievements, Indian agricultural R&D has a long way to go to realize its full potential.

(i) Human Resources

The success of any organization depends largely on the commitment of people who work for the organization. Scientific temper and culture of creativity is much less in Indian agricultural research system compared to the developed countries. Most of the agricultural scientists of public NARS in general consider research as a ‘business as usual’ activity without having a quest for acquiring knowledge, securing creativity and pursuing problem-solving. Those, who work harder and have relatively better achievements, are treated at par with under-performers. Many professional journals are not of high standard and have a weak referee system. The number of research projects/schemes also rose over the years which warranted recruitment of more scientists. The increase in number of scientists brought in its fold dilution in quality. More than 95 per cent of the agricultural scientists are in the public institutions and their track record in efficient use of resources has been far from impressive (Jha and Kumar, 2006). Low capital intensity is not providing adequate operational back up to scientists. Merit, instead of being a key determining factor, has become as one of the factors in recruitment of scientists for NARS. The cumulative effect of all these developments has adversely impacted the quality of the human resources involved in scientific inquiry. The standard of PhD degree has got diluted in terms of its rigour over time. A large section of agricultural scientists in recent decades earned their PhD degrees from the SAUs of their respective states where they are working, resulting in severe inbreeding and decline in the quality of the graduates and it continues to be a serious pitfall of Indian NARS. Besides, gradual weakening of proper linkages among academic institutions has also added to the deterioration in quality of education and research (NAAS, 1999).

While in Land Grand Universities in the USA, professors specialize in teaching and/or research or extension without affecting their specialization, In Indian SAUs, scientists/professors are involved in all the three functions of research, teaching and extension with frequently changed work places because scientists

[2] The MNCs which lead research in seed and agrochemicals are Monsanto, DuPont, Dow, BASF and Bayer. Some of the leading national companies which take up seed research are Mahyco, Rasi Seeds, Nuzi veedu, JK Seeds, and Indo-American Hybrids. Mahindra & Mahindra, John Deere, and TAFE take up research in tractors and farm machineries. Jain Irrigation and NETAFIM are companies involved in micro irrigation research.

are transferable across various centres. This kind of environment has led to lack of specialization hampering taking-up of advanced research. The majority of the scientists want to work in a city/town or in teaching campuses and resist to work in Zonal Research Centres (ZRCs). At the end of the day, science becomes a victim of this kind of poor governance. Universities, often, could not be able to put in place the full strength of scientists in a multidisciplinary research project due to paucity of funds or recruitment policies of the government. Both in ICAR and SAUs, though mechanisms are in place to identify the research problems through interaction with stakeholders and scientists, agricultural scientists do not get sufficiently sensitized on field problems. This phenomenon often raises the question of even relevance of research. Not only that, most agricultural scientists do not have inclination to take up basic and strategic research as they are not strong in basic sciences.

(ii) Research Infrastructure

In any research system, the adequate and quality infrastructure alongside its regular maintenance is important to effectively utilize the potential of scientists and to achieve better efficiency in research. In the Indian NARS, ICAR institutions are better equipped in terms of infrastructure since ICAR being a central government organization, is in a vantage position to get the required funding to strengthen the infrastructure. But, ICAR zonal research stations in remote areas function with limited infrastructure. The SAUs are frequently the victims of poor funding support for infrastructural development. Budget deficits and bureaucracy cause delay in channelling the funds from the respective state governments. A lion's share of the funds go to salary and allowances of regular employees (about 75% of financial support provided by the state government) and, of the remaining 15 per cent, large part of it is used for meeting the operating costs. Only 10 per cent of the total budgetary provision is available for infrastructure which is hardly sufficient to meet the upkeep of the existing infrastructure. Obviously, modernization of research infrastructure is not moving forward at a pace, it is expected to move.

(iii) Finance: Mobilization and Allocation

Several previous studies and reports have brought out about underfunding and allocative inefficiencies in public research in agriculture (Pal and Byerlee, 2003). First, there is no clear concept of budgetary support to agricultural R&D by the government administration though it is accepted that one per cent of agricultural GDP may be allocated for agricultural research. An examination of data reveals that research intensity was hovering between 0.48 and 0.73 during 1999-00 to 2006-07(ICAR, Agricultural Research Data Book, 2009). This ratio matches with the average research intensity of 0.60 estimated for the developing countries, but is much below 2.4 per cent allocated by the developed world as a whole (NAAS, 2009). However, the continuing tight fiscal situation at the central and state levels is often used as an alibi not to meet such commitments (Jha and Kumar, 2006). Though the target of one per cent was fixed for the 9th Plan, it has not been fulfilled even in 11th Plan. This research intensity varies across the Indian states, reflecting the poor sensitivity of the political leadership and bureaucrats on research funding. The agricultural research investment during the past two decades by public and private sectors is shown and Table 1. The public sector which invested ₹ 7137 million (in current prices) in 1990-91 increased ten-times touching an amount of ₹ 78140 million in 2008-09. The private sector has also increased its investment at the same rate as the public sector. However the share of private sector in the total investment has remained between 4 per cent and 6.3 per cent. In the case of allocation of research resources across commodities, the relative value of the commodity in total value of agricultural production was used as a major criterion. Nearly 40 per cent of the resources found the way for research on foodgrains and horticultural crops (ICAR, 2009)

The SAUs receive 60 to 70 per cent of the budget from the respective state governments; it covers three-fourths of the salary of staff and the remaining part is met from ICAR and other sources. Though about 20 per cent of the funding comes from ICAR, almost 70 per cent is allocated under All India Coordinated Research Projects. According to Pal and Byerlee (2003), about 12 per cent of funding support from ICAR was through competitive funding. Normally, it was channelled under cess fund scheme. Afterwards, this scenario changed and presently, ICAR does not

Table 1. Investment in agricultural R&D by public and private sectors

(in million ₹ at current prices)

Year	Public	Private	Total	Share of private to total (%)
1991	7137.0	231.7	7368.7	3.14
1992	7718.0	352.0	8070.0	4.36
1993	8329.0	431.3	8760.7	4.92
1994	9599.6	504.5	10104.1	4.99
1995	11063.2	558.2	11621.4	4.80
1996	12149.8	814.4	12964.2	6.28
1997	13663.1	844.2	14507.3	5.82
1998	15156.9	1018.4	16175.3	6.30
1999	19603.9	1784.5	21388.4	8.34
2000	25023.0	1069.2	26092.2	4.10
2001	29859.9	1005.1	30865.0	3.26
2002	33232.4	1235.0	34467.4	3.58
2003	34983.4	1550.8	36534.2	4.24
2004	38409.6	2111.6	40521.2	5.21
2005	41190.7	2535.7	43726.4	5.80
2006	45703.9	2400.1	48104.0	4.99
2007	49355.9	3282.3	52638.2	6.24
2008	68514.8	3213.9	71728.7	4.48
2009	78140.4	3206.8	81347.2	3.94

provide funds under competitive funding, except in the case of special projects, viz. NATP, and NAIP[3].

The closing of cess fund scheme by ICAR has resulted in misery to hundreds of scientists who want to take up independent projects addressing local issues and special problems. ICAR has not created any alternative channel of funding under competitive mode. The ICAR Reorganization Committee (2005), headed by R.A. Mashelkar, has recommended a competitive grant scheme indicating at least one-third of the funds earmarked for research should be given on a competitive grant basis. The biggest problem with NARS remains that it is strictly governed by the same rules and regulations relating to expenditure and filling up of positions as are operative in the government departments of states and the centre (11 FYP document, 2008). Universities generate 5-8 per cent of the internal accruals by selling seeds, bio-inputs, consultancy, etc.

The SAUs, despite their existence for almost half a century, have not been able to ensure a stable funding mechanism commensurating with their requirements. As a result, they face moderate to acute financial hardship. The SAUs receive funding from state government under two heads: Non-Plan and Plan. While Non-Plan provision is meant for schemes which are of permanent nature (core budget for running the colleges and research stations), the Plan head provides funds for identified schemes under research, and education, and production of seed (breeder seeds) and bio-inputs. The Plan schemes have well-defined durations and can be continued or closed. In the SAUs, proportion of funds allocated between Non-Plan and Plan is, broadly, 60:40. The proportion keeps fluctuating over years. Outcome of these schemes are not rigorously reviewed, except a few queries raised by the Finance Department of the state government. The frequent transfers of Secretary to the Government

[3] NAIP envisages accelerated transformation of Indian agriculture through technological innovations by the public research organizations in partnership with private sector research, and other stakeholders. World Bank has lent ₹ 920 crores as credit and GOI has funded ₹ 230 crores (one crore is 10 million).

(in this case Principal Secretary, Agriculture) has not ensured proper understanding of and real need for budgetary allocations to the University. More often, the degree of interest in agriculture by the Agricultural Secretary and the Finance Secretary decides the quantum of allocation.

Besides Non-Plan and Plan provisions, the state government allocates ₹ 10-15 million annually under Part II Plan schemes exclusively meant for funding research projects of immediate importance or for creating specific infrastructure. This provision can also be reduced unexpectedly (in a financial year) by either the State Planning Commission whose approval is necessary for budgetary allocation or by Agricultural Secretary to accommodate other purposes within the agricultural ministry. Thus, funds made available from the state government are not adequate for doing research at the SAU level and hence funds for research projects are mobilized from other sources[4]. In the mobilization of funds from other sources, not all SAUs are successful. Even-though the annual growth rate of research expenditure is estimated to be 7 per cent, the annual salary increments, increases in dearness allowance and rise in the cost of operating costs just compensate the enhanced budget. But, the growth in allocation to research in real terms is much smaller.

At the SAU level, the Vice-Chancellor and Director of Research must effectively communicate with the Minister for Agriculture and Secretaries to the Government, Agriculture and Finance, on the need for enhancing the budget under plan schemes, covering all important research projects which are specific outcome-oriented. In addition, the SAUs must find innovative ways of mobilizing financial resources. It may include commercialization of their technologies, encouraging the scientists to go for consultancies, motivating them to propose projects for external funding, joint research activities with other institutions and private sector. There lies a tremendous scope to partner with the private sector with due respect to protection of IPRs and benefit-sharing.

(B) Private Sector R&D

The national agricultural R&D system has undergone a structural transformation with the enlarged role of private sector during the past two decades. One of the significant developments is the entry of MNCs making a sizeable investment in research on seed, agrochemicals and agricultural machinery. The private sector investment in agricultural R&D has been accompanied by consolidation of chemical, seed and biotechnology companies. Expansion in the private sector R&D has been motivated primarily by advances in biotechnology-strengthened IPRs, globalization of markets, and new opportunities to collaborate with public sector institutions. With the decontrol of regulations, the private research expenditure increased by 70 per cent between 1985 and 1995 (Pray and Fuglie, 2002) in India and the momentum is continuing. The trend in private sector investment on agricultural R&D during the past two decades is depicted in Table1. In the year 1991, private sector investment on research was only of ₹ 231.7 million and by 2009, the investment got multiplied by almost 14-times[5]. The companies which have made investment in agricultural research fall in the categories of seeds, fertilizers, agrochemicals, agricultural machinery and sugar. While machinery, seeds, and agrochemicals categories have shown an increasing trend in R&D investment, fertilizer and sugar companies have not raised the level of research investment over the years (Figure 1).

(i) Seed

Recent years have witnessed a different story with more farmers using hybrid seeds of cotton, maize, millets, sunflower and vegetables with rice hybrid slowly picking up. Many seed firms have now focused their attention on the development of single cross hybrids in maize.

For example, with a market share of 35 per cent in India's corn seed market, Monsanto India is upbeat on new hybrids Dekalp, Supreme, Pinnacle and 900 Gold and continues investing on maize research (Financial Express, 20 Aug, 2010).

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[4] The other sources include ICAR, DBT, DST, Ministry of Renewable and Non-Conventional Energy, Medicinal Plants Board, World Bank Projects funded through GOI, Ministry of Water Resources, and Private donors.

[5] The private sector investment on agricultural R&D reported here comes from 71 companies as provided in Annual Reports of Ministry of Science and Technology, Government of India. There are many other companies, both national and MNCs, not included for want of data.

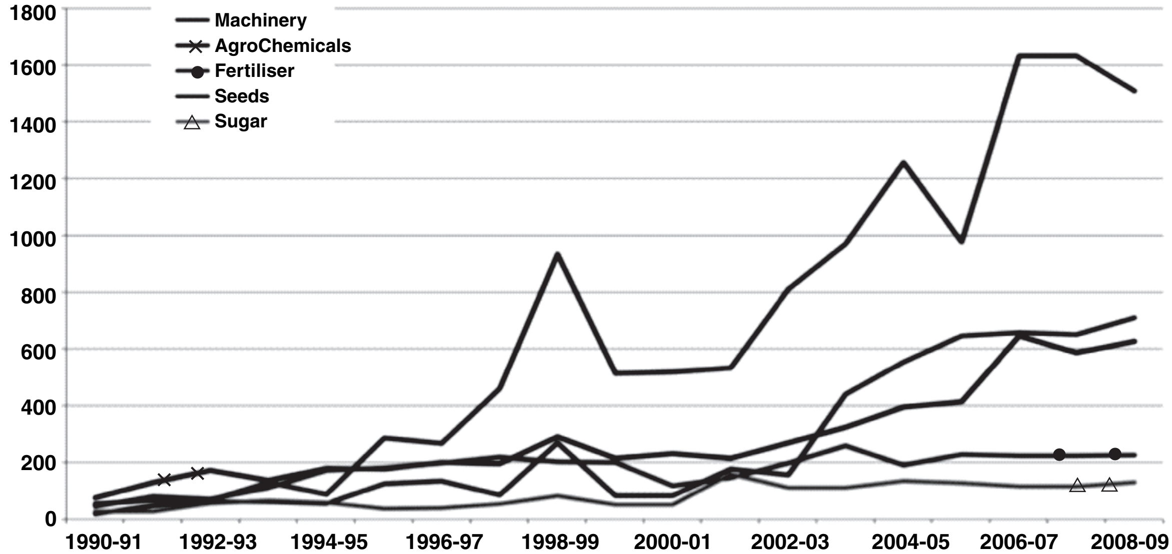

Figure 1. Private investment in agricultural R&D by input category. Vertical axis shows rupees in million

Crop breeding research is being conducted over large acres for maize nurseries and over hundreds of acres of farmland for hybrid product testing across different agro-climatic conditions and seasons in India by both public and private sectors. The Seed Policy of 1988 had opened up new vistas and the private seed companies started investing in the seed development and marketing. Biotech crops are delivering higher yields. Though this development occurred in North America, Indian government policy and MNCs' interest to expand business helped the transfer of technologies such as GM crops to India. The success story of Bt cotton has not been replicated to other crops because of the weak stand taken by Indian government on approval of new GM technologies. R&D in plant biotechnology is capital-intensive and consumes more time for the release of a technology due to delay in the approval processes. Therefore, seed industry is in need of more stable operating environments and appropriate regulatory process to make further investments in the emerging technologies. On the regulatory front, the Patent Act, 1999 and the PPV&FR Act 2001ensured IPR, an encouragement to the private sector, have attracted more MNCs to invest in both R&D and seed production and distribution in India. Further, the new Seed Bill passed in 2011 will create the right environment to accelerate investment in the seed sector.

The ICRISAT provides private inbred lines and intermediate varietal products for developing improved variables of OPVs and hybrids in crops such as pigeon pea and groundnut. The private sector strengthens their activities by sourcing breeder seed from ICAR and SAUs. The performance of private sector in seed production business has become superior as the private firms have been commercializing and marketing new varieties more efficiently through their networks than the public sector does. The liberalization of Indian economy since early-1990s has opened up opportunities for MNCs dealing with agro-inputs, seeds and agricultural machinery to expand their activities in India and many of them have launched joint ventures[6]. Thus, the private sector agricultural research has achieved a credible performance contributing to increase in TFP in Indian agriculture.

(ii) Fertilizers and Agro-chemicals

Fertilizer products are largely the outcome of R&D efforts of the private sector, particularly the MNCs. The consumption of chemical fertilizers has doubled in a period of fifteen years. The industry is developing fast in terms of using the latest world class technology in manufacturing processes to prepare innovative new products. R&D on fertilizers can be categorized as one relating to fertilizer production and the other relating

[6]Few important examples are Monsanto – Mahyco, and E.I.D Parry.

to consumption. On the production side, research comprises fertilizer production processes, product development, and market research and supply chain and is carried out by both public sector and private sector R&D units of the respective fertilizer manufacturing companies. Besides 9 large public sector fertilizer companies, 15 private sector fertilizer companies have established strong in-house R&D centres. Over the years, to ensure that it is well prepared to meet the challenges of fast-changing world and remain the market leader in the industry, the fertilizer R&D centres are involved in the in-depth surveys to understand the market demand and plan their production. These centres are spearheaded by highly qualified and experienced scientists; engineers and technologists. R&D centres with research outputs are supporting the companies to deliver timely, cost-effective and market-focused solutions. Now the emphasis of private sector R&D units of fertilizer companies is on creativity and ingenuity to develop products most suitable for the end-users. They are also seeking the recognition by the Department of Scientific and Industrial Research, Govt. of India and look for obtaining patents and allow the researchers to publish scientific papers.

For significant yield losses in foodgrains due to pests and non-essential herbs, agrochemicals application has proved to be an effective solution[7]. The sheer size of Indian agriculture has virtually attracted every MNC from all over the world to India to tap its potential. The consumption of pesticides per ha was around 450-500 grams as against the world average of 2.5 kg/ha in the year, 2008 (Pesticides Manufacturers & Formulators Association of India, 2010). However, according to industry leaders, though the physical quantity of consumption has declined, the value of agrochemicals consumption has gone up. It is because that the new chemical molecules (invented) are recommended at lesser doses due to their high effectiveness. The dynamics of product development in agro-chemicals show that newer and newer products are being introduced in the market due to technological advancements and competition. Since beginning, the leading companies pursued applied and adaptive research on plant protection. Further, the government taxation policy was favourable for the import of R&D equipment which encouraged research in developing pesticides, fungicides, and herbicides, as a part of their global research activity to develop products which are environment-friendly, easy to apply and less hazardous to human beings and at cheaper cost.

The leading agrochemical producers have a strong in-house R&D unit. The MNCs transfer the technologies developed in one of their R&D units located outside India when needed. Leading national and multinational companies apart, a number of small-sized companies are involved in production and sale of agro-inputs. These companies take the help of retired scientists from research organizations, chemists, and engineers to formulate their own versions of inputs. These companies do not have the required R&D facilities. Resorting to copying the technologies of standard input companies is not uncommon in developing the products. For the production of inputs such as bio-pesticides, bio-manures, bio-fertilizers, small machinery and implements, the small companies source the technologies developed at the public research institutions.

(iii) Agricultural Machinery

The continuous quest for higher productivity in the global agricultural markets has a direct effect on the demand for engine-powered products. Though tractor was the key machinery all along in the process of agricultural mechanization, now there is large-scale use of harvesters, threshers, weeders and sprayers. Farmers in India are now seeking improvements in work efficiency with more powerful machinery embedding more sophisticated features. Private R&D develops current generation equipment providing farmers with all levels of power and higher efficiencies. The new models of machinery are expected to be more productive. Now, a number of databases are available and used for forecasting the models. Currently, there are about 19 tractor manufacturers in India (Agricultural Research Data Book, 2009). So also the research relating to farm machinery is again a part of global effort. Research on tractors has relatively a long history in India. Though original designs were of foreign origin, Indian companies focused research to

[7] In the supply chain starting from production to consumption, up to 35 per cent of total food produced is lost due to insect pests, plant pathogens, weeds, rodents, birds and nematodes (NAAS, 2009)

vary the sizes and capacity of tractors and their attachments to perform different activities. In the past two decades, MNCs, New Holland and John Deere, have entered the Indian market. But research continues in improving the models for achieving higher efficiency and making it cheaper. The adaptive research is taken up in India to make the machines to perform better in local conditions. A large number of small-scale agricultural machinery, equipment and implements manufacturers are spread across the country. The R&D in these small-sized firms cover designing implements for attachments. Function-specific machines such as rice planter and sugarcane harvester are still imported. The companies are having linkages with public research system to test their equipment in the field conditions.

The decade beginning 2011 will witness fast spread of micro irrigation technology given the scenario of water scarcity due to growing demand for water. There are about 74 drip irrigation companies in the country which are creating significant impact. Jain Irrigation Systems Limited and NATAFIM Irrigation Private Limited are the leading companies taking up research. However, the drip and sprinkler technologies must be refined and improved to realize greater benefits. R&D in micro irrigation must get priority in investment. Private companies having known the huge market ahead for micro irrigation are investing sizeable quantum of funds on R&D in micro irrigation.

4. Early Success Followed by Failing Agricultural R&D

Despite several achievements, a big gap still remains in agricultural R&D between the targets planned initially and achieved. Some of these are:

- Economic viability of farming is deteriorating and farmers' suicides continue.
- Farmers' average yields of even irrigated rice and wheat are significantly below the demonstrated yields in the farmers' fields.
- Yield per unit of water or per unit of fertilizer is still moderate, not the best.
- Yields of rain-fed crops remain stagnant. Varieties /hybrids are not bred exclusively for rain-fed environment with high drought-resistant character and grain quality traits demanded by the farmers of these regions.
- No breakthrough technologies even in rice and wheat for enhancing the potential yield levels since the green revolution period.
- Research not focused on improving resource-use efficiency and subsequent cost reduction in crop production[8]
- Rapid growth in private R&D has taken place in the recent past, particularly after the entry of multinationals. So far public system has not responded to this in terms of adjustments in their research and investment portfolios. There are areas of comparative advantage which need to be taken into account. The public research agenda has to make space for private research without losing core capacity. Further, according to various review committees, public research system is suffering from imbalances in functional allocation of resources, poor monitoring and evaluation, duplication, and bureaucratic rigidities (GoI, 2005).
- Organization and storage of experimental data generated over the years on crop breeding, and management of plant nutrients, pests, weeds, water, soil fertility, and use of agricultural implements and machinery is very poor by the agricultural scientists in India. There is no systematic and comprehensive compilation of innovations in spheres other than breeding (Vaidyanathan, 2010). An in-depth and detailed analysis of these data will help to get new insights and to design new research projects which can address the crop management problems precisely.

[8] There is a definite scope to improve fertilizer-use efficiency, to design cost-effective plant protection methods, to enhance productivity per unit of water and to achieve labour saving by proposing appropriate mechanical technologies. In-depth research by applications of basic principles of agronomy, crop physiology, soil science, microbiology, agricultural chemistry and agricultural engineering is essential to achieve breakthrough management technologies. The scientists concerned with above disciplines do not show the kind of enthusiasm andcommitment to understand the basic aspects of science to invent breakthrough technologies.

- Social scientists in Indian NARS have failed to do quality research to help understanding the problems in non-adoption of technologies and give right kind of feedback to agro biological scientists to work on real nature of problems.
- In general, the political leadership has always opted for populist kind of policies such as extending subsidies to agriculture in different forms and is not inclined to support R&D, infrastructure and market development programs.
- Indian agricultural scientists have not conceived the concept of R&D in-depth (they don't differentiate between research and R&D) as they are able to bring out good research output or generate a technology but do not have the concept of packaging and commercializing or popularizing. This is one of the main reasons that technologies stay in the shelves.
- With the start of the globalization of Indian economy since mid-1990s, marked changes have occurred in the growth of Indian agriculture, as has been stated elsewhere in this paper. Agricultural R&D, particularly public sector research, continues to appease itself with claims of past successes, often limited to varietal release, while productivity growth has stagnated and disciplinary commodity knowledge development has tapered-off.
- The goals of agricultural research have not changed in recent decades because the early emphasis on food production has to be replaced by a much broadened focus on poverty alleviation, environmental degradation, social inclusion and agri-business development. Conversely, agricultural research system in India has proved remarkably resistant to the concomitant need for changes in research focus. As a result, the national research system is under great strain.
- The 11th Five Year Plan document identifies the following critical gaps in agricultural R&D:

Lack of integration of traditional and modern biology to achieve both yield and quality aspects; need for public research in hybrid development with commercial viability at least in crops such as pigeon pea, soybean and mustard; failure to enrich nutrients in rain-fed crops transferring genes from indigenous plant types; initiating research program on impact of climate change on agriculture; research thrust on balanced and site-specific nutrition and water management strategies; improving IPM research fully integrating across various plant protection sciences; and utilization of biodiversity in horticulture to achieve tolerance to stresses and quality of the produce. The plan document further indicates the need for taking a comprehensive view of the functioning of agricultural research system and systematic change to improve its functioning. The document also points out the failure to optimally utilize the available resources because of lack of a clearly stated strategy that assigns definite responsibilities, prioritizes the research agenda rationally, and recognizes that research mode is not always best suited for product development and delivery. Besides, the R&D system suffers from the dominance of commodity-based research, forgetting to focus on holistic approach, strict compartmentalization of R&D agencies, i.e. lack of flow of information among research, extension, and implementation departments; lack of large-scale on-farm validation of techniques and feedback thereon, leading to practically no scope for their refinement (11th Plan Document, 2008).

5. The Way Forward

(i) Galvanizing Existing R&D System

The National Agricultural Policy (NAP) formulated in the year 2000 asserts that agricultural growth will critically depend on improved R&D processes. The policy emphasizes the new paradigm of regionalization of research based on well-defined agro-climatic regions, application of frontier sciences, participatory and proprietary approaches in R&D, strengthening research–extension linkages, and a well-organized, efficient, and result-oriented agricultural R&D system to achieve higher growth rate in Indian agriculture and to sustain it. Recognizing the need for revamping the public R&D in agriculture, several internal and external reviews were undertaken over the past two decades. Mutatis mutandis facility of making necessary alterations in instruments of governance remains mostly unutilized. ICAR has generally sacrificed its autonomy in favour of government rules and procedures, observed G.V.K. Rao Review

Committee in 1988 (NAAS, 2002)[9]. But no serious follow up was pursued to implement those recommendations of reviews.

Bureaucratic governance — The present departmental mode of organization and management of public systems of agricultural R&D need to be moulded in an innovative system framework. Neither the institutes nor the ICAR headquarters was able to function in a truly autonomous manner (ICAR Reorganization Committee, 2005). The prevalence of dominating and bureaucratic system has to give way to a more flexible and liberal administration. The personnel policies must be such that these provide an environment for the scientists to become highly creative and productive. Their work must lead to solving developmental problems. This is to be coupled with carrying out the 'development' component of R&D system. At present, in public research system, the marginal productivity of an individual scientist is almost zero. There is a large scope to make it optimal-sized and more productive. Basic and strategic research, the precursor of productive applied research, critical for developing breakthrough technologies and problem solving applied research can be confined to institutes with highly qualified human resources and needed infrastructure and multi-disciplinary orientation in both ICAR and SAUs. Other centres can concentrate on adaptive research, technology testing and seed production activities. Since the productivity of disciplinary/subject matter research has reached a plateau, a system oriented, interdisciplinary, issue-based approach is the need of the hour. This will necessitate reorganization of research at functional levels (institutes and research stations).

SAUs may also have the same model as of ICAR. That way, many of the redundant centres may be closed and the resources can be redeployed so that each centre may be endowed with adequate resources. There must be an effective planning, monitoring and evaluation system in place to make the whole NARS highly creative and productive and to realize the stated policy goals. Day-to-day administrative system must not stifle the activity, liberty and individuality of scientists such as getting training, procurement and exchange of research materials, hiring research assistants and support staff and ensuring the right project team and so on. And the new norms of accountability of research staff must replace GoI and state government regulations and ensure the quality in research to achieve excellence and globally competitive science. SAUs have, largely, been reeling under traditional administrative system framed four decades ago, resulting in poor management of resources, physical, human and financial, often discouraging scientists to be more creative. The agricultural universities may redefine their mission, reorganize management and create a most favourable environment for researchers. This is needed because Indian agriculture now has expanded clientele and has mutable objectives. The demand pattern of agricultural products, both raw and processed, has changed with the fast growing purchasing power of about 300 million middle class population.

Financial support and decentralization — Further, though financial decentralization has been suggested time and again, what has been done is not enough. The research intensity estimates provide evidences of funding for public agricultural research continues to be stressed, and that too more pronounced at state level. There is some amount of uncertainty and also inefficiency in allocation of funds both by central and state governments. The development of a policy framework through consultative mode on the role of public, private and international players and levels of research investment by sector is critically needed to make NARS most efficient and to realize the expected contributions. SAUs experience adverse effects on human resource development, research infrastructure, and taking up new research projects due to shortage of funding. There is an urgent need to sensitize policymakers at the state level to the payoffs to investing in research. The central government at the same time could provide support to weaker states and extend incentives to stronger states to increase their funding in the form of matching grants. To sustain research funding for relevance and quality of research and to achieve efficiency in the system, a higher share of funding may be gradually shifted to competitive funding. However, the block grants may be continued to support and upgrade research infrastructure and human resources and to pursue basic and strategic research. The public NARS, simultaneously, must take efforts to generate internal revenues through getting

[9] ICAR has earned the distinction of 'a most often reviewed scientific organisation in the country'.

payments for services extended to the commercial farmers, commercialization of technologies, and contract research with the private sector. The scientists in public R&D must be imparted knowledge in IPR and business skills to commercialize technologies and services. The central and state governments may come together to provide a lump sum grant as core fund to maintain and renew the infrastructure and to fund core research activities to obviate the uncertainty in funding.

With its effect on productivity, agricultural research ranks among the key factors driving growth in agriculture. That is why World Bank assistance to national agricultural research system (NARS) has been increasing since the mid-1960s. India was benefitted through major World Bank supported projects, viz., NARP, NATP, AHRDP, and NAIP. These projects helped to develop research infrastructure and human resources of Indian public research system in a big way. One of the weaknesses of Indian planning in use of World Bank assistance is insufficient appreciation of economic analysis in research planning, particularly by the managers at GoI level, thus not achieving the most efficient use of borrowed resources. Poor integration of research planning at the central and state levels and among institutions has also posed problems, leading to wasteful overlap (Purcell and Anderson, 1997). Sustainability of financial support by external agencies will come not only from the efficient use of resources but also from how relevant are the technologies generated in terms of translating into productivity.

Performance tracing — At present, the performance of ICAR institutes and AICRPs is assessed through quinquennial review teams (QRTs). A thorough examination of this system is required in the context of new developments in planning, monitoring and evaluation system (PME) to improve the effectiveness of the review. Performance of individual scientists is done through annual assessment reports (AAR). The assessment proforma is outdated and not suitable for current trends in assessment of a scientist. Since AAR is confidential in nature, a scientist's performance is not made available to the individual unless he/she gets 'below average' performance. And structural mechanisms must be introduced to build the competencies of individual scientists in the deficient areas.

There is a need for strict accountability system to evaluate scientists based on utility of research outputs or their relevance to stakeholders. In order to empower scientists, project based budgeting (PBB) can be institutionalized as practised in international agricultural research centres and national institutions like Council of Scientific and Industrial Research (CSIR). The agricultural innovation system of the country needs an internal thinking mechanism and a more professional approach much like TAC of CG system to identify, steer and evaluate arenas of agricultural knowledge and technology generation and its application. Both central and state systems can consider this approach. Besides, reorganizing and expanding bodies like Research Advisory Committee (RAC) of ICAR and Governing Councils of SAUs will make them to play a more effective role. The performance of SAUs is rarely evaluated. There is no external evaluation system. NAAS (1999) has suggested constituting a standing committee for each state with Secretary, Department of Agricultural Research and Education (DARE) as Chairman, officers from state government as members and Deputy Director General (Education), ICAR as Member-Secretary. It will be difficult for the DG, ICAR (Secretary, DARE) to be in the committee given his other responsibilities. The Committee, alternatively, must have an eminent scientist as chairman and leading scientists /experts in different fields, respective secretaries to state government (agriculture /finance) and one or two leading farmers and agro-industrialists as members. The committee may have periodic monitoring of the functioning and provide timely guidance. The Committee shall put in place effective mechanisms for impact assessment and evaluation including accountability for the administrative, financial, and academic achievements for the respective university.

Unfettered proliferation of SAUs — During the past one decade, bifurcation and trifurcation of agricultural universities within the state is going on. It is often a political decision without looking into the real need for it. These new universities are also not adequately supported with financial, physical and human resources. It is more of competing for the same level of resources available during pre-bifurcation period leading to suffering of both the existing and newly created universities. It often leads to dilution in quality of research and education. At the national level, a set of criteria must be developed to go for new universities and must be demand-driven one. It is absolutely essential to bring private/government colleges and faculties in the general universities offering programs in higher education in agriculture into the fold of agricultural universities and the ICAR, for improving the quality of education and research because the institutions are academically of very low standard with no monitoring and control system.

Need for strengthening social science research — There is a need to strengthen social science research in agricultural innovation systems to enhance the social and ecological learning capacity of R&D organizations. It is important as well for agricultural policy analysis and to design R&D strategies and to build bridges between policy makers and research system of both public and private sectors and farmers (NAAS, 2002). International agricultural trade has become an integral component agricultural development in India, more so, since implementation of AoA in 1995 under WTO requirement. The immediate objective was to make India more competitive to succeed in world trade in agricultural commodities. However, the response of agricultural R&D system to the changing trade scenario has been slow and less comprehensive. Recent experiences unequivocally suggest targeted approach to derive benefit from WTO. R&D programs, therefore, should accord priority attention to targeted export commodities; pursuing research on production to consumption; strengthening research in frontier areas of agricultural sciences to achieve reduction in cost of production and quality improvement.

The Indian agricultural research system has been struggling to manage the multiple objectives ranging from traditional food security to emerging demands to serve a more market-oriented economy, meet the needs of high-end consumers, and preserve environment. Achieving a balance between these objectives has major implications for organization of research and prioritization of the research agenda. Among the reforms in research management which need immediate attention is institutionalizing priority setting mechanisms because Indian agricultural research system is large, objectives are conflicting and clients are poor in articulating their research needs. Research managers should be exposed to priority setting exercises and made to realize its importance[10]. This should be followed by assigning roles and responsibilities at different levels to achieve the objectives. The social scientists must make adequate efforts to institutionalize priority setting mechanisms in the Indian NARS.

Institutional linkages —The NAP enunciates that the application of science and technology in agriculture will be promoted through a regular system of interface between S&T institutions and the users. There are several effective partnerships and coalitions in technology generation, development and dissemination in India and elsewhere and these models can be adopted to make NARS a more result-oriented system. The linear model of technology generation and dissemination in spatially and functionally differentiated organizations must give way to a non-linear model of continuous participatory learning within the larger agricultural innovation system including the private sector. Indian NARS is in need of a strong research-information system. Scientists in ICAR and SAUs are in wider isolation not knowing each other's work, often overlapping their research work. One of the requirements of research proposals then must be that a new research proposal has to take into account the same research going on elsewhere using the database. Hence strengthening the research information system in the form of a portal making is mandatory to post the details of on- going and recently completed successful projects; the electronic communication among the scientists will improve the exchange of information and quality of research management. The proposals may indicate the expected social, economic and environmental benefits due to the project.

Some of the applied research like crop and resource management research generating information based on disembodied technologies having a low appropriability in short-term, may not attract private research investment. Therefore, public sector role is important to provide disembodied technologies. Accumulating body of evidence indicates increasing trend in private investment in applied research, i.e. development and

[10] Most of the agro biological scientists are not exposed to the concept of priority setting and also the importance socio-economic dimension of research problems in the Indian research environment.

dissemination of embodied technologies. This trend should be encouraged by liberal industrial and regulatory policies, placement and effective enforcement of intellectual property rights, besides providing basic research support and creating linkages between needs of public and private sectors (Pal and Singh, 1997).

(ii) Can PPP Play an Effective Role in Invigorating Agricultural R&D?

Public–Private Partnerships (PPPs) in agricultural R&D are being increasingly viewed as an effective means of conducting advanced research, developing new technologies, and deploying new products for the benefitof small-scale, resource-poor farmers. PPP is any research collaboration between public- and private-sector entities in which partners jointly plan and execute activities with a view to accomplishing agreed-upon objectives while sharing the costs, risks, and benefits incurred in the process. The three expected benefits with respect to PPPs are : (1) whether public–private partnerships contribute to reducing the costs of research, (2) whether they promote innovative research, and (3) whether they enhance the impact of research on smallholders and other marginalized groups (Spielman *et al*., 2007). The aim is to use complementary assets to maximum advantage. The partners must agree to objectives, roles, responsibilities, and incentives. They also need to jointly protect and benefit from intellectual property, and work towards a unified vision of enhanced farm productivity.

Why are PPPs vitally important? Public investment in productivity-enhancing agricultural R&D has been declining in most of the world outside China. Private investments and capability, on the other hand, continue to grow. These trends open up the need and opportunities for R&D partnerships that pool assets to farmers' benefit. While the public sector provides strength in crop improvement, private organizations contribute expertise in plant sciences, genomics, bioinformatics, and the marketing and delivery of products and services. PPP in agricultural R&D is increasingly emerging as an effective means of conducting research in frontline areas of science and technology, commercializing new technologies, and deploying new products for the benefit of small-scale farmers, food-insecure consumers and other marginalized groups (Pawar, 2010). The partnerships offer a means of tapping the strengths of various partners and channelling knowledge and resources into areas where they can address complex development problems. The private sector plays a particularly critical role in spurring agricultural R&D, especially when combined with public sector initiatives within mature markets with strong intellectual property rights (IPR) to protect returns on investment. This synergetic effect enables returns on investment by taking advantage of the private sector's technical expertise, and the public sector's knowledge of local needs and networks (Syngenta Foundation, 2012).

(i) Respective Roles

Agricultural R&D and extension in India has become more pluralistic in recent years. The robust growth of agricultural knowledge and information system is also the consequence of strong agricultural research system built over time. Though the public sector has played a dominant role in the whole process, private sector's role cannot be underestimated. Its contribution in the development of hybrid seeds in cotton, sunflower, maize, sorghum, pearl millet and vegetables is well known. Besides new seeds, its role in the development of pesticides, fertilizers, weedicides, farm machinery and agro-processing technologies deserve special mention. It is, however, a common knowledge in the Indian context that, while the public sector focusses its research on foodgrains, oilseeds, sugarcane etc. which are characterized by high volume lower profit seed production, the private sector concentrates on low volume higher profit hybrid seed production. The public sector's output with high public good character has addressed the food security and livelihood issues of millions of small farmers and poor sections of population. On the other hand, the private sector research output has helped the development of agri-business in the country.

The recent trend is that private sector has been in the forefront in bringing out the products of biotechnology and transferring them to the farmers[11]. In spite of this kind of few specific achievements in

[11]Spread of Bt cotton is the solid example of this trend. Monsanto's sharing of Bt genes with Mahyco in order to develop the Bt cotton and Mahyco's further sharing of Bt genes with many other Indian seed companies has revolutionized the cotton production in the country within a short span of five years.

recent times, Indian NARS remained stagnated as reflected from the lack of agricultural productivity growth and deceleration in TFP. ICAR has initiated the process of development of public-private-partnership in agricultural research[12]. ICAR – SAU system, though shared germplasm to a limited extent with the private sector, is not fully open to share the knowledge and products with the private sector. So also the private sector has remained closed to share knowledge. The public system has always looked at the private system as a profit-making entity. The reality is that private sector has made farming more economically viable through the spread of hybrid seeds and other modern inputs. CGIAR had a much broader vision of collaborating with private sector[13].

(ii) Approach and Strategies

Material exchange — At present, agricultural policymakers need to ensure a conducive environment where public and private research complement each other and synergize both the streams whereever there is a common space. At present, PPP is in the transition phase and experiences an environment of asymmetric information. There exists lot of potential for sharing of seeds, planting materials and biotech products. Even vegetatively propagated materials such as sugarcane variety can be shared by settling with a lump sum payment. The access to materials is constrained by bureaucratic hurdles and inefficiency in transfer of materials. The implementation of PVP&BR Act and Biodiversity Act has put additional restrictions in exchange of germplasm. There is an urgent need to smoothen these impediments through better interpretation of new regulatory provisions to make PPP in agricultural R&D more efficient. FAO has already approved the Standard Material Transfer Agreement (SMTA) for sharing the germplasm with a benefit sharing mechanism.

Allocation of research responsibilities — Public sector must allocate more resources to pursue the basic and strategic research in identified institutes, and university departments utilizing advances in S&T which will provide a strong platform to achieve breakthroughs to develop frontier technologies. For specific areas of upstream research, PPP will be more ideal as exemplified by the DBT – Mahyco partnership on plant genomics. There exists vast scope to propose research proposals for funding jointly which most donors prefer and promote. ICAR has approved several such projects under National Agricultural Innovation Project (NAIP)[14]. There is general consensus that the public sector can work on genetic variability, development of in-breds, CMS lines and semi-finished or intermediate products and selection of markers which can be shared with private R&D to develop new products which will sharply reduce time involved between basic/strategic research and products ready for commercialization. The national policy framework needs to be developed to promote PPP and has to have provisions for negotiations among the public institutions and private firms. The Tropical Asian Maize Network (TAMNET) whose members include public and private from Asia, established in 1993, manages locational evaluation and annual field trials conducted throughout the region and resulting data across countries are synthesized and shared among countries.

Creating consortium — ICAR institutes and SAUs can create consortium in which the private seed companies can become members and access the technologies available with these institutions[15]. Similar arrangement can be made for sharing parental lines developed in public sector for hybrid seed production

[12] ICAR had organized ICAR-Industry Meet during July, 2010 at Delhi and had a wide range of discussions on strengthening PPP in commercializing public sector technologies and promoting agricultural research. Since early-1990s, government is following an open door policy for MNCs to market their products in India. Imports of seeds and planting materials were liberalized.

[13] With its location in India, ICRISAT had opened its doors for their products (varieties, parental lines and germplasm), and crop management knowledge to both private sector and Indian public system alike.

[14] NAIP is supported by the World Bank in the form of loan to Government of India for the purpose of strengthening agricultural R&D. Under NAIP, ICAR / SAUs and other leading research organizations such as IITs and general universities who will do the research and forward the results for agribusiness applications to the private sector thus are encouraging PPP in agricultural R&D.

[15] Private sector may deposit a nominal amount to become the member of the consortium. In Tamil Nadu Agricultural University (TNAU), this arrangement is working well for improved varieties of paddy and small machinery and equipment, plant protection and food processing technologies released by the University.

by the private sector on a benefit sharing basis. In this case, the particular crop variety may be exclusively licensed to a company but the Institute / University will have the right to multiply and market the agreed product concurrently to benefit the small farmers. The private company will have to label the product with the name of the original inventor institution.

Pricing of inputs — Some of private firms fix prices for their products often leading to out-of-reach of the small farmers. Generally, farm inputs are price elastic. Hence, the firms must be reasonable in fixing prices. Whenever warranted, public sector research institutions can assist the government in pricing inputs of private sector scientifically by analyzing all the relevant information. This advisory role will lead to a win-win situation for both the parties.

Sharing infrastructure and contracting research — Since public sector does not have market / dealer network as that of the private sector, public sector can enter into agreement with private sector to promote products of the Institute or University. A reasonable profit-sharing arrangement is not out of reach of both the parties. The unique feature is that researchers from both types of institutions will participate in the whole chain. Both public and private sectors can encourage contract research mutually[16]. This way, the researchers from the institutions not having such high-end infrastructure are greatly benefitted. ICAR/SAUs must open up its infrastructure to the private sector at reasonable service charges. The public system must have business incubators wherein the small and medium level entrepreneurs can use the public facilities and develop their products. As agricultural and biotechnological research is capital-intensive and requires huge funding, PPP mode can effectively use the existing infrastructure and exchange materials such as genes carrying defined traits[17]. The need of strengthening research infrastructure is widely felt among the researchers who, for example, have indicated the requirement of National Phytotron facility in more centres of crop research to carry out increased number of indigenous transgenic events, gene isolation, construct development and event testing.

Vertical and horizontal integration — According to the Central Insecticides Act, agro-chemicals companies have to get their new products tested by the public research system as a requirement for release of the products. The private firms pay testing fees to the public institutions. In many cases, there is undue delay in testing the products. In the future, once a product (chemical, seed, mechanical) or a technology is to be released by the private firm, the ICAR-SAU system must facilitate in terms of testing it with very nominal fees and time efficiency and encourage the private sector to have a positive frame of mind. Networking of institutions will be one of the arrangements to share information, knowledge, IPR, HRD and financial resources. ICAR-SAU system has networking of institutions under coordinated projects but it is unidirectional and often not useful for addressing the local problems[18]. Collaborative efforts will expedite this process so that farmers are benefitted in a shorter time span. The international collaborative project, CIMBAA, shows the way for collaboration[19].

PPP research with human face — One of the criticisms is the lack of interest by the private sector in the case of orphan crops. This is one area where PPP can work on research projects with human face as it addresses the problems of small and rain-fed area farmers. The PPP in agricultural research must be designed keeping in mind that the research outputs are accessible and relevant to the needs of the resource-poor end users. Further, international agricultural research shall have to be adequately integrated with

[16] For example, ICRISAT has biotech facilities and offers DNA testing, sequencing and analysis services to all groups of researchers by charging a fee. Similarly, National Bureau of Plant Genetic Resources (NBPGR) of ICAR offers customized protocols for event specific testing.

[17] The joint efforts of Mahyco – TNAU – UAS (Dharwad) in developing the Bt Brinjal will be an eye opener to other institutions and private firms to adopt this model.

[18] NAIP model of bringing together public and private institutions in applied research, product/technology development and value addition in the supply chain and also involving NGOs in dissemination of technologies wherever needed has tremendous potential to make research more of a problem-solving and productive activity.

[19] CIMBAA stands for Collaboration on Insect Management for Brassicas in Asia & Africa. This is a collaborative research jointly supported by ICAR, AVRDC, University of Melbourne, NRI, University of Greenwich, Cornell University and Nun hems, India.

regional and national partners covering public and private sectors (GCARD, 2010). In developing countries, the share of private sector in the total agricultural research investment is only 6.3 per cent as against 55.2 in the developed countries (http:asti.cgiar.org). PPP in biotech research is exemplified by a number of programs now on—going in Africa. Developing biotech bananas in Uganda with increased vitamin A, vitamin E and iron content is one such project. Successful research of this kind could dramatically improve the diets of millions of people[20]. Partnerships can also bring orphan crops within the scope of research, benefitting disadvantaged communities. Researchers in private sector teamed up with the University of Bern to maintain and improve yields of tef, the most important cereal crop in Ethiopia (Crop Life International, 2009).The private sector consortium funding of pearl millet research at ICRISAT in Asia region has considerably increased the Institute's ability to generate scientific information and improved breeding lines and parental lines of potential hybrids as international public goods which benefit not only the consortium members but also public sector programs worldwide (Mula *et al*., 2007).

IPR management — One of the PPP issues in agricultural biotechnology research is IPR management and there is vast scope to arrive at a mutually agreeable arrangement by considering the nature of research work, investment made and risk taken by each partner in a given project. Further, in the case of public sector, research is more of supply-driven rather than demand-driven. The feedback from private seed companies is that market-oriented traits are often not available in the products of public sector. This kind of engagement makes both public and private partners that research must be more market relevant and their research programs are complementary rather than competitive.

Private sector feels the difficulties in accessing the germplasm available with National Bureau of Plant Genetics Resources (NBPGR) in India. Germplasm resources of public and private sectors must be treated as a national wealth which must be usable for research purposes without much of hassles. The seed associations can play an important role in acquiring the needed materials available with public sector[21]. This kind of approach is very much replicable at the national level[22]. In Indian NARS, biotech companies are approaching ICAR institutes and select SAUs by assigning marker selection job by meeting the cost. One of the proposals is the creation of a consortium of markers at the national level by standardizing the markers[23]. It helps to achieve fast tract breeding which is the common objective of both the sectors. Sharing advanced lines of public sector with private sector may speed up assessment of the performance of the lines with adequate security against misuse. It is also frequently suggested that a Steering Committee may be constituted involving public research institutions, industry and policymakers to consider and speed up the PPP activities. Accelerated commercialization can be achieved by identifying the right product, application screening, and market analysis for the product and business development by using the strength of both the sectors. Negotiated IPR arrangement will buttress the convergence of public and private units in specific activities.

[20] Under Bio Cassava Plus project, public and private sector research is focused on enhancing levels of zinc, iron, protein and vitamins, as well as post-harvest durability. It will benefit 250 million people of sub-Saharan Africa. Africa Bio Fortified Sorghum project is a public private consortium developing a more nutritious and easily digestible sorghum. The African Agricultural Technology Fund (AATF) has worked with some of its private sector partners to negotiate licensing agreement of proprietary technologies that allow royalty free access and sharing of these technologies in order to improve farmer access. The project covers main staple foods such as maize and rice. The sustainable tree crops program (STCP) has been established on PPP mode. STCP launched in 2000 by the West and Central African cocoa stakeholders, World Cocoa Foundation, and USAID and managed by International Institute of Tropical Agriculture (IITA). The introduction of innovations in production, marketing and instructional management has led farmers to increasing their cocoa yields on average by 15 to 40 per cent.

[21] For example, AVRDC was funded by a group of companies for identification of a marker(s) to the extent of US $180 thousand. Marker(s) were given back in two years with a condition, that markers become open source.

[22] In the ICAR – Industry Meet held during July, 2010 at Delhi, a policy decision was made to hold such meetings annually to strengthen the linkages between public and private sector R&D.

[23] Monsanto has published 3000 markers which are to be tested in Indian conditions. For example, J K Seeds, Hyderabad, is testing some of these markers. IARI, New Delhi, has developed kits for a set of companies on demand.

Improving the governance — In the context of growing globalization, both public R&D institutions and private companies experience market demand from foreign countries for their research products such as seeds, agricultural machinery, agro-chemicals and services. The inter-ministerial approvals cause enormous delays in supply to the foreign markets. A single window system for export of products and services will improve the competitiveness of Indian agricultural R&D. In order to improve the access to information, public research system must develop a good database which is accessible to the private companies (as a registered member) resulting in better understanding of research results, products and services of public sector.[24] Further while much is talked about sharing of materials and knowledge by public to private, there is explicit indication from the private sector about their interest in extension, sharing of facilities, participation in seed delivery and development of business management system for the public sector only to a limited extent. It is possible that government can fund extension activities of the private sector on a selective basis.

Partnership in biotech and agricultural machinery industry — In the Indian context, the private sector has been more successful in development and marketing of biotech products such as Bt cotton and public sector has not done so. But, there is insufficient profit motive to induce private sector to undertake biotech R&D needed by small farmers (Byerlee and Fischer, 2000). In order to support small farmers, both the public and private sectors possess complementary assets needed for biotechnology to be applied to its full potential. Thus, in line with ADB's Private Sector Development Strategy (ADB, 2000), PPP programs are encouraged by the DBT (GOI) in promoting biotech industry. This is to promote innovation, pre-proof-of-concept research, accelerated technology and product development in biotechnologies related to agriculture and other areas (DBT, Annual Report, 2007-08).

The public sector research, particularly, ICAR-SAU system, has developed concepts, models, methods, designs and prototypes in the area of agricultural tools, implements and machinery (small scale). Further, public research institutions also take up field testing of machinery and agronomic research for the use of machinery, implements and tools for various operations covering different crops and locations. Private sector has to upscale and commercialize these technologies which public system cannot handle and also do not have the mandate to do that. Whenever private sector needs research support, it can be contracted to the public research centres. But, the private sector is experiencing difficulty with only a few accredited testing centres leading to delays in completing the testing process. Further, states within India have different standards for machinery testing causing repeated testing. Public research system has to obviate these kinds of constraints and give the feedback to the private sector R&D on the working of their products in the field. Quality assurance of the products will be a major challenge for the government. Independent accreditation agencies can be entrusted with these functions since resting the responsibility with government departments will lead to lot of corruption and delay.

7. Outlook and Policies: Agricultural R&D

The future of Indian agriculture will be one of knowledge and technology intensive and wider dissemination of the same can not be accomplished in isolation. All categories of players, viz. public and private, and large and small must be involved in promoting the technologies. The agro-input industry has to closely work with government to realize the objectives. Policy environment must ensure a continuous encouragement to the private sector for attracting more investment. Mechanisms can be evolved for accreditation of private R&D, MOU for forging functional relationships and protocols for transferring/sharing technologies, materials and unique facilities. There is ample scope for intensifying human resource development through initiation of fellowships and professorial chairs by the private sector in focused areas of research. Private sector has a good amount of expertise which can be used in agricultural management process within NARS.

Even though the share of agriculture in GDP has declined to one-fifth from one-half at the time of Independence, agriculture remains the predominant

[24] According to private sector, often full information such as early maturity, grain quality, etc. are not available for public sector hybrids, leading to redoing some of the testings, etc. adding to the cost of seeds.

sector in terms of employment and livelihood provision for more than half of India's workforce engaged in it as the principal occupation (11th Plan Document, 2008). Agriculture still contributes significantly to export earnings and supplies raw materials to many industries. To achieve a higher rate of agricultural growth in order to meet the demands of increasing population (expected to reach 1.63 billion by 2050), technological advancement will be very critical. India's phenomenal success in cotton production in recent years is due to adoption of Bt technology. The advances in biotechnology and their integration with plant breeding will pave the way for achieving higher yield crops. In the significant advances India has made in agriculture during the past half-a-century, the role of agricultural input industry is very significant. The expansion in the use of seed, fertilizer, agrochemicals, irrigation and agricultural machinery industry has occurred parallel with the growth in productivity of rice, wheat, cotton, corn, sunflower, soybean, sugarcane and vegetables. While the public sector R&D, extension, and seed supply has made substantial contributions to food and non-food crops production, agri-business companies have been working with government to reach out to farmers in the supply of agricultural inputs used from sowing to harvest.

In the case of agricultural biotechnology, most R&D was undertaken up by agrochemical and seed companies, and it was these companies that began investing in biotechnology in a big way. The seed cum agro chemicals industry saw a rapid increase in both vertical and horizontal concentration from early-1990s. The multinationals which dominate the biotech, seed and agrochemicals in India and other developing countries are: Monsanto, Syngenta, Dow, DuPont/ Pioneer Hi-Bred, Bayer Crop Science and BASF. These corporations had their roots in the pharmaceutical and or in the chemical sector. Monsanto and DuPont/ Pioneer are focusing their investments in seed and biotech R&D while Bayer, Syngenta, BASF and Dow are focusing chemical crop protection R&D. Their continued activities in the R&D are important to innovate and bring out more efficient inputs to agriculture.

There is an urgent need to strengthen public research system in terms of efficiency, evolving technologies to address problems in the order of priority, and strengthening PPP wherever it is more beneficial. Policy environment and governance system must be in place to achieve the goal of maximizing benefits of agricultural R&D.

References

Alston, J.M., Chan-Kang, C., Mara, M.C., Pardey, P.G. and Wyatt, T.J. (2000) *A Meta-Analysis of Rates of Return to Agricultural R&D: Ex pede herculem*?, IFPRI Research Report No. 113, Food Policy Research Institute, Washington D.C., 2000.

Beintema, Nienke, Adhiguru, P., Birthal, Pratap S. and Bawa, A.K. (2008) *Agricultural Research Investment in India*, Policy Brief 27, NCAP, ICAR, New Delhi, 2008.

Bhushan, S. (2005) Total factor productivity growth of wheat in India: A malmquist approach. *Indian Journal Agricultural Economics*, **60**(2): 198-210.

Byerlee, D. and Fischer, K. (2000) Accessing modern science: Policy and institutional options for agricultural biotechnology in developing countries, *World Development*, **30**(6): 931-948.

Cororaton, C.B. (1998) *Rates of Return to R&D Investment in the Philippines*, Philippine Institute for Development Studies, Makati City.

CRIDA (Central Research Institute for Dry land Agriculture) (2007), *Vision-2025*, Hyderabad.

Crop Life International (2009) *Advancing Agricultural Innovation through Public – Private Partnerships*.

Evenson, R.E., Pray, C. and Rosegrant, M.W. (1999) *Agricultural Research and Productivity Growth in India*, Research Report No. 109, International Food Policy Research Institute, Washington D.C.

GoI (Government of India) (2005) *Report of the Task Group on Revamping and Refocusing of National Agricultural Research*, (Chaired by M.S. Swaminathan).

GCARD (Global Conference on Agricultural Research & Development) (2010) *Conference Proceedings*, Organized by Global Forum for Agricultural Research, at Montpellier. 28-31 March.

Hazell, P. and Ramasamy, C. (2009) *The Green Revolution: Reconsidered*. The Johns Hopkins University Press, Baltimore. 242 p.

ICAR (2009) *Agricultural Year Data Book- 2009*, India Agricultural Statistical Research Institute, New Delhi.

ICAR (2009) *Report of ICAR Reorganization Committee,* chaired by R.A. Mashelkar.

Jha, D. and Kumar, S. (2006) *Research Resource Allocation in Indian Agriculture*, Policy Paper 23, National Centre for Agricultural Economics and Policy Research, New Delhi.

Kumar, P., Kumar, Anjani and Mittal, S. (2004) Total productivity of crop sector in the Indo-Gangetic Plain and of India, *Indian Economic Review,* **39**(1): 169-201.

Kuznets, Simon (1965) *Economic Growth and Structure*, WW Norton & Co, New York, pp. 244-5.

Mula, R.P., Rai, K.N., Kulkarni, V.N. and Singh, A.K. (2007) Public-private partnership and impact of ICRISAT's pearl millet parents research, *An Open Access Journal* (Published by ICRISAT), **5**(1): 1-5.

NAAS (1999) *Reorienting Land Grant System of Agricultural Education in India*, National Academy of Agricultural Sciences, New Delhi.

NAAS (2002) *Scientists' Views on Good Governance of an Agricultural Research Organization*, Policy Paper 17, National Academy of Agricultural Sciences, New Delhi.

NAAS (2009) *Agriculture Sector: Status and Performance*, *State of Indian Agriculture*, National Academy of Agricultural Sciences, New Delhi.

National Commission on Farmers (2005) *Serving Farmers and Saving Farming- 2006-07: Year of Agricultural Renewal*, Third Report, Ministry of Agriculture, Government of India, New Delhi. pp. 1-24.

Pal, Suresh and Singh, Alka (1997) *Agricultural Research and Extension in India: Institutional Structure and Investments*, NCAP Policy Paper 7, National Centre for Agricultural Economics and Policy Research, New Delhi.

Pal, Suresh and Byerlee, Derek (2003) *Funding and Organization of Agricultural Research in India: Evolution and Emerging Policy Issues*, Policy Paper 16, National Centre for Agricultural Economics and Policy Research, New Delhi.

Pawar, Sarat (Union Minister for Agriculture, GOI) (2010) *Inaugural Address: ICAR-Industry Meet*, 28 July.

Pesticides Manufacturers & Formulators Association of India (2010) Indian Pesticides Industry-Market Research Report, *Top Feeds News*, 6 October.

Planning Commission (Government of India) (2007) *Report of the Steering Committee on Agriculture and Allied Sectors for the Formulation of the Eleventh Plan*, New Delhi. pp. 12-15.

Planning Commission (Government of India) (2007) *Report of the Steering Committee on Agriculture for the 11th Five Year Plan*, New Delhi.

Planning Commission (2008) *Document of Eleventh Five Year Plan, 2007-12: 1. Inclusive Growth, Vol.1*, (Chapter 1, p.1), and *2. Agriculture, Rural Development, Industries, Services and Physical Infrastructure*, Vol. 4 (Chapter 1, p.1 and Chapter 4, p.79), Oxford University Press, New Delhi.

Pray C.E. and Fuglie, K.O. (2002) *Private Investment in Agricultural Research and International Technology Transfer in Asia*, International Potato Center, Rutgers University, and Economic Research Center, Bogor, Indonesia.

Purcell, D. and Anderson, J. (1997) *Agricultural Extension and Research: Achievements and Problems in National Systems*, World Bank Operations Evaluation Study, World Bank, Washington D.C.

Ramasamy. C. (1997) *Return to Research Investment in Agriculture*, in Proceedings of International Workshop on Integrating Research Evaluation Efforts, edited by M.C.S. Bantilan and P.K. Joshi. ICRISAT, Patancheru.

Spielman, D., Hortwich, F. and Grebman, K. (2007) *Public-Private Partnerships in International Agricultural Research*, Research Brief No.9, International Food Policy Research Institute, Washington, D.C.

Syngenta Foundation for Sustainable Agriculture (2012) *Public Private Partnerships: Teamwork Achieves Many Goals*, Brief Report, Basel, Switzerland.

Swaminathan, M.S. and Bala Ravi, S. (2007) The Indian agricultural research system, in *Agricultural Research Management,* edited by G. Loebenstein and G. Thttappilly, Springer, The Netherlands, pp. 305-29.

Vaidyanathan, A. (2010) *Agricultural Growth in India – Role of Technology, Incentives, and Institutions*, Oxford University Press, New Delhi. pp. 170-181.