Minireview Article

Resurrection of Indian Agriculture through revolutionary innovations of science and technology

ABSTRACT

Aim: The manuscript discussed on current and future challenges of Indian agriculture and recent innovations of science and technologies to achieve increased productivity, profitability and sustainability for Indian agriculture.

Background: Agriculture is the most important sector of Indian economy, but after involvement of more than half of the workforce in this sector, the contribution towards national GDP is still declining, due to the prevalence of the challenges like lower productivity, depleting resources, biotic and abiotic stresses, uncertainty in climate, higher yield gaps, and low farmers income.

Data sources: Data sets and policy papers are from Government organizations and research articles from referred journals were used.

Conclusion: With the use and adaptation of revolutionary innovations, Indian agriculture can reform and overcome the limitation of low resource use efficiency, abiotic and abiotic stresses, and post-harvest losses.

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Key Words: *Indian agriculture, Science and technology, Innovations*

INDIAN AGRICULTURE: AN OVERVIEW AND WAY FORWARD

India is a developing nation with a population of 1.3 billion that is likely to surpass that of China by 2022, resulting in increased demands for food, feed, and fiber. India produces food for about 17% of the human population and 15% of the livestock population using only about 2.4% of the geographical area and 4% of the renewable water resources in the world [1]. Therefore, we cannot afford to neglect our farmers and farming. The number of households engaged in agriculture in 2011 (119 million) was much higher than those in 1951 (70 million). Besides, the landless agricultural labors numbered 144.30 million in 2011 against 27.30 million in 1951 but after involvement of such a huge population the contribution of agricultural sector towards the national economy are declining (fig.1). Therefore, the welfare of this elephantine portion of India's population is predicated upon a strategy for robust agricultural growth that is guided by an income enhancement approach. However, the average income of an agricultural household from July 2012 to June 2013 was quite low as Rs. 6,426, (fig.2) compared to the average monthly expenditure of Rs. 6,223. Approximately 22.50% of farmers were living below the poverty line [1].

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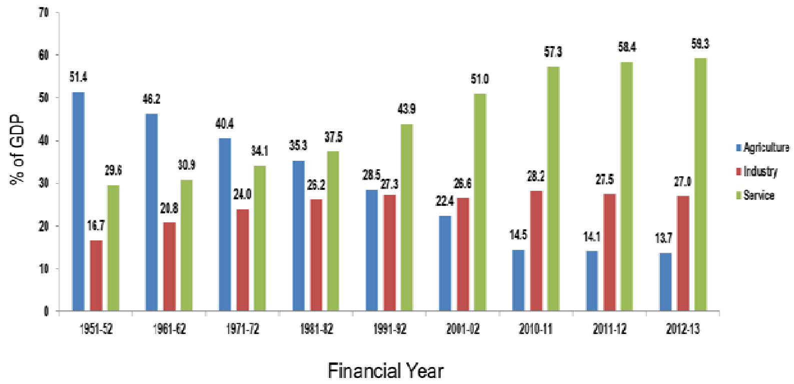

Figure 1: Sector wise contribution of GDP of India (%). [2]

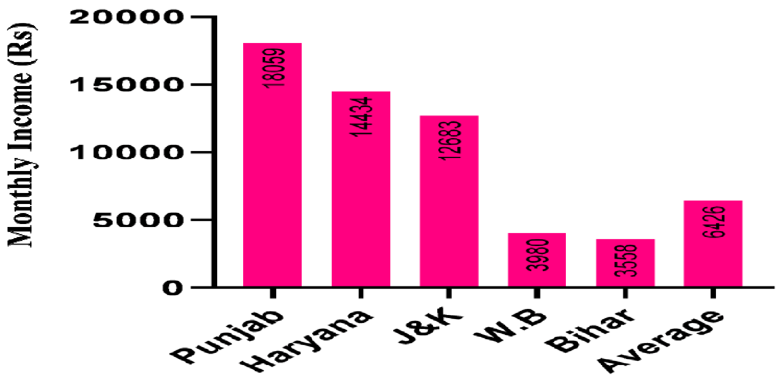

Figure 2: Average monthly farmers income (Rs.) [3]

Ironically, these same farmers are now caught in a vortex of more serious challenges. Farmers' suicides account for approximately 10% of all suicides in India. The reasons for this menace include inflated prices of agricultural inputs, monsoon failure, climate change, high debt burdens, government policies, mental health, personal issues and family problems [4].

Agricultural resources such as land, water, and labor, face competition from non-agricultural sectors in India. The gradual increase in environmental degradation through intensive cropping systems leads to resources depletion; declining soil fertility, rising water table depth, rising salinity, and resistance of harmful organisms to pesticides is now of great concern to us. The net sown area in India has remained more or less the same for almost 40 years; however, the number of farmers has increased over this period. Consequently, the average operational holding size has shrunk to

1.15 ha (fig.3) and approximately 85% of the farmers are operating on less than 2 ha of land; thus, increasing smallholder farms' productivity is becoming critical [1]. Similarly, the irrigated area in the country is about 65.7 million ha, which is 47% of the net cultivated area, and the remaining 53% of land is rainfed and vulnerable to climate change. Water availability has also been steadily diminishing per capita, from 5177 m^3 in 1951 to 1820 m^3 in 2001 and to 1588 m^3 in 2010 due to increased population, rapid industrialization, urbanization, cropping intensity, and deteriorating and depleting groundwater water resources [1].

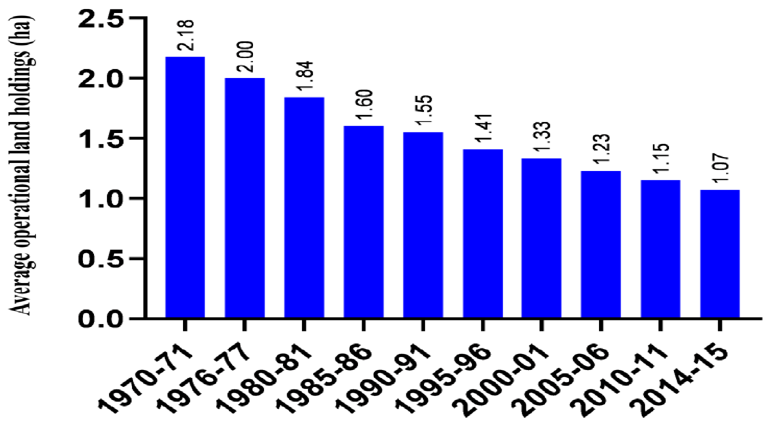

Figure 3: Average size of operational land holdings (ha) [5]

India faces a huge challenge in growing more food and sustainably with limited resources under rising temperatures and erratic monsoons which result occurrence of different biotic and abiotic stresses. Another major problem is the yield gaps in food crops. One way to enhance agricultural yields is to identify the magnitude and causes of gaps existing between attainable and current yields and identify the management and/or biophysical factors that are closely associated with these gaps [6]. These yield gaps can be narrowed down, by providing easily accessible and actionable information on which management factors should be promoted to enhance food productivity. In India, regions under rain-fed agriculture have large yield gaps in food crops and therefore, these regions will have great potential for increasing production in the future [7]. On average, soybean, rice, mustard, and wheat produce less than 50% of their maximum potential yield. Therefore, reducing the yield gap is pertinent in states including Uttar Pradesh, Bihar and other Northeast states characterized by large yield gaps [8].

As mentioned in the Federation of Indian Chambers of Commerce and Industry (FICCI) report (2015), the agricultural sectors' labor force has been declining over the past decade. Therefore our focus should be on the shortage of labors and finding solutions to increase yield and productivity. There has been an increase in the workforce in the non-agricultural sector at the rate of 6 million per year since 2004-05, while, the same has declined in the agricultural sector by around 30.57 million (259 million in 2004-05 to 228 million in 2011-12) [9]. Higher remuneration and growth of opportunities in alternate sectors are leading the workforce away from agriculture. Consequently the increase in labor wages and intensive use of fertilizers, pesticides, and herbicides has escalated of cultivation costs and thereby lower income to farmers'.

The Green Revolution using science, in India enabled the nation to overcome frequent famines outbreaks and hunger related deaths. In the future, the adoption of science and technology with the support of pragmatic policies will be the key to transforming India's agrarian economy. In Rosegrant *et al.*'s study (2014) it is reported that, if no-till, drip irrigation, sprinkler irrigation, drought tolerance, heat tolerance, precision agriculture, nitrogen use efficiency, crop protection, water harvesting, organic agriculture, and integrated soil fertility management with positive yield impacts, were adopted together for maize, wheat and rice, their production cost could reduce by 49%, 45%, and 43%, respectively [10]. Hence, scientific innovations all along the agricultural value chains will be imperative for India to augment productivity as well as provide farmers income and livelihood security. Here an attempt is made to review the scientific technologies and innovations that would address our agrarian crisis and transform the economy and ensure food and nutritional security of the nation.

1. Innovations for crop production aspects

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a. Resource use efficiency and crop management

During post-Green Revolution period of 1970-71 to 2010-11, India's food grain production grew by approximately 2.3 times and fertilizer (NPK) consumption increased approximately by 13 times (fig.4). Consequently, the average crop response which was 50kg of food grain per kg of NPK fertilizer during 1970-71, dropped to 18.70 kg during 2010-11 [1]. The increase in fertilizer use is a major contributor to the crop production costs with a significant budgetary burden on the nation economy and the fiscal burden of fertilizer subsidy, which went from 60 crore in 1976-77 to 72,437.58 crore in 2016-17 along with soil fertility deterioration. Farmers' incomes and nation's economy can be enhanced by productivity gains, reduced cultivation costs, and remunerative price. To increase income, we have to increase resource use efficiency, mainly for fertilizer and water. Currently, soil fertility maps have great use, which are prepared by analyzing soil samples collected on the basis of global positioning systems. These maps give an idea of soil fertility status and help to monitor soil health from time to time. In India, Himachal Pradesh is the only state with a total soil fertility map and farmers are reaping benefit from it.

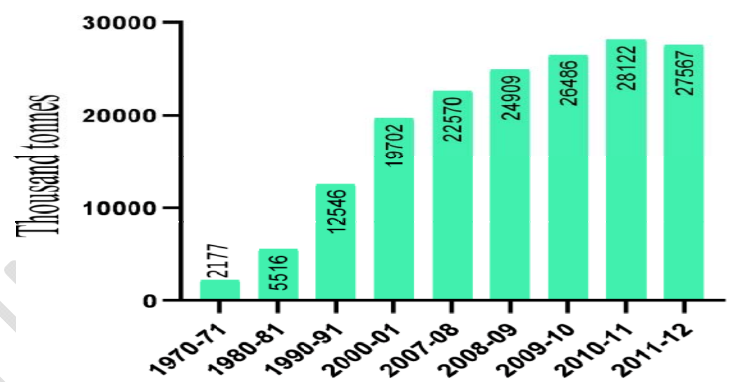

Figure 4: Trends of fertilizer consumption by India (Thousand tons) [11].

Another primary factor of production-water- is also under stress. Global water consumption is doubling every 20 years, more than twice the rate of population increase [12]. Mismanagement and unsustainable use of water are making the situation worse in India. Therefore, rainwater-harvesting structures have to be developed to improve water use efficiency, agricultural productivity, and ground water recharge and this will help reduce soil erosion [13]. Irrigation Association of India's study (2016) results show that under micro-irrigation, fields save 50-90% irrigation water, 30.5% energy, 28.5% fertilizer, and increase yield by 42-52%, depending on crop and environment, as compared to traditional irrigation systems. The successful deployment of rainwater harvesting in Gujarat, helped in increase farmers' income, maximum by 68%; the average income of all 13 districts was 42% [14]. Along with rainwater harvesting, watershed projects of the state, reported an increase in ground water (more than 1 m); 60% reported increase in cereal yield and 62% reported increase in yield of cash crops [15].

In populated countries with profligate economic development, such as, India, China, and Africa, the arable land is rapidly dwindling due to urban construction and other industrial land uses. In this context, an innovative cultivation system may be an option. For example China's Gobi agriculture uses, desert-like non- arable hectares of land and the abundantly available solar energy for year round crop production in controlled environments. Here, clusters of individual cultivation units are established using locally available materials; land productivity is 10-27 times higher and efficient crop water use is 20-35 times greater than traditional open-field, irrigated cultivation systems. This creates rural employment, which in turn improves the stability of rural communities and plays a role in enhancing the national economy [16].

b. Digitally driven decision support system

Automation of agricultural mechanization is an intensive area of research and development with emphasis on enhancement of food quality, preservation of operator comfort and safety, precision application of agrochemicals, energy conservation, and environmental control. Digitally driven precision agriculture is gaining prominence not just in countries with huge tracts of agricultural land and rich farmers but also in countries with small tracts of agricultural land, such as China.

Although the agricultural technology information center and the training-and-visit (T&V) system recorded remarkable levels of technology adoption, it had some shortcomings. For example, the farmer's yield and exerted productivity vis-à-vis extension efforts were difficult to measure accurately, only one recommendation was given to all farmers per village, regardless of different soil health status; and too much concentration was put on the crop sub-sector at the expense of lives-stock, fisheries, forestry and natural resources management sub-sectors [17]. Moreover, in this system, farmers rely on the knowledge and experience of the village level extension officers, who may not always stay updated. Crop based mobile applications (e.g. Rice Doctor developed by IRRI) and Web 2.0 platforms where farmers and crop experts have real-time discussions can play significant roles in overcoming of T&V system's inadequacies.

Agribusiness giants such as John Deere and Monsanto–Climate Corporation have introduced digital devices to couple farm mechanization with real time data collection and farm condition assessment for precision farming. These include sensors compatible with tractors, robots, unmanned aerial vehicles (UAVs) to collect real-time farm data, remote GPS tracking units, and Internet of Things and Big Data for real time field information. This data-driven agriculture will transform our current agriculture 2.0 into agriculture 4.0 and will help with precise input requirement, yield monitoring and mapping, average moisture, and seeding variety and rates. Artificial Intelligence (AI) takes automation to another level, by incorporating analysis and learning based on past and current data. It further adds to the scope of automation in decision-making, where the integration of multiple and varied information is interpreted to balance a desired set of outcomes. AI planting application has been developed by the Microsoft in collaboration with ICRISAT, helping the farmers for determining optimal date to sow, for which they don't need to install any sensors in their fields or incur any capital expenditure [18]. Farmers who use these methods would not only maximize the yields but also reduce the operating expenses, and increase profits.

In a developing country like India, farmers are neither cash-rich nor do have easy access to formal financial sources to invest in buying farm machinery. To address this challenge, innovative models, such as custom hiring centers, have emerged that makes mechanization more effective and affordable for farmers. Here machinery is given on rent basis that reduces the farmers' capital requirement, the productivity and income can be increased even with a labor shortage.

The crop loss assessment, which is a crucial step in crop insurance and government compensation, is currently based on the traditional method of collecting data by the village-level rural agricultural extension officers. This is time consuming, less reliable and unauthentic. Therefore, remote sensing data can be used to spatially locate and analyze the damaged area. In India, the KISAN Project [C(K)rop Insurance using Space technology And geoiNformatics] of Ministry of Agriculture and Farmers Welfare envisages the use of space technology and geoinformatics (GIS, GPS and Smartphone) along with high resolution data from UAV/drone-based imaging to improve the yield estimation and crop cutting experiments planning needed for the crop insurance programme. An Android application designed and launched by ISRO (National Remote Sensing Centre, Hyderabad), helps in real-time collection of data on hailstorm occurrences, along with photographs and geographical coordinates (longitude and latitude), and support more objective crop loss decision [19]. Because *Nitiayog* (National Institute for Transforming India) has suggested that farmers grow more high-value crops to increase profit, the government has developed a CHAMAN project where geoinformatics are used to estimate crop area and production of horticultural crops in selected districts of major states (12 states, 185 districts). This program envisages using of satellites, remote sensing, and GIS to generate action plans for horticultural development [20].

c. Innovations for biotic and abiotic stress management

Annually, Indian agriculture suffers a loss of about 30-35% crop yield of US $36 billion due to insects and pests [21], which adversely affects the agricultural economy, food security, and farmers' incomes. Genetically modified crops and genome editing techniques are powerful tools for developing future crop varieties with in-built genetic resistance to various biotic and abiotic stresses to reduce crop losses and enhance input use efficiency, yield potential, and quality traits. In the past, Bt cotton has shown tremendous success, as between 2000-01 and 2016-17, cotton production increased from 14million bales (170kg) to 35.1 million bales and yield increased from 278 kg/ha to 568 kg/ha. This enabled India to become the world's leading cotton producer, accounting for 26% of the global cotton production, and made India the second largest exporter of cotton, with exports rising from US $0.9 billion in 2005-06 to a peak of US $4.9 billion in 2011-12 [22]. Further, adaptation of Bt cotton has reduced chemical pesticide use by 37% and increased farmer profits by 68% [23].

Crop breeders can rely on new breeding approaches, such as, AgRenSeq and speed breeding, to shorten the development period for resistant varieties. The AgRenSeq or rapid gene cloning technique developed by the John Innes Centre (U.K.) will accelerate the fight against pathogens by rapidly screening resistant genes from wild relatives of modern crops and inserting them into the crops [24]. Speed breeding was developed by Australian scientists to accelerate the genetic gain; it can increase wheat crop growth to three times the regular speed and enables six generations of the crop to be produced each year using controlled temperature and extended photoperiod [25].

Farmers can now minimize crop loss by smart advanced predictions mobile applications. These applications compare current weather to historical data on weather conditions that are conducive to a particular plant disease, and then calculate whether it makes sense to spray fungicide or not, thereby reducing pesticide use and increasing spray efficiency [26].

Keeping the biotic stress apart to combat abiotic stress due to uncertainty in climate change, phenotypic plasticity in plants is a viable option. Phenotypic plasticity is the ability of an individual organism to alter its physiology/morphology in response to changes in environmental conditions. By increasing phenotypic plasticity of crop varieties, future abiotic stress resilient varieties can be developed. A phenotyping platform with automated non-destructive imaging-based scan analysis of crop growth needs to be developed to accelerate breeding for drought and other abiotic stresses. Different traits need to combine in various selection indices to assist breeders in producing desired phenotype for the specific agro- climatic conditions. Understanding the stress physiology and the metabolic pathways that regulate various stresses is needed for genetic enhancement and field phenotyping of crops.

2. Innovations for postharvest management

Although, India is one of the world's largest food producers, the country's food banking network estimates that 15% of the population goes hungry every day. One in four children are malnourished and 3,000 die daily from illnesses related to poor diets. At the same time, India wastes 40% of harvested agricultural produce (e.g., 3.9% -6% cereals, 4.3%-6.1% pulses, 2.8%-10.1% oilseeds, 5.8%-18.1%fruits, 6.9%-13% vegetables, 6.7% poultry and 10.5% marine fisheries) [27], which is more fruits and vegetables than the U.K. consumes and more grain than Australia produces each year. . Food wastage also commits grave economic damage, costing the nation over 92,651crores (2014-15 estimate) which is nearly one and half times of the national union agricultural budget (2018-19), i.e. 58,080 crores [27]. Postharvest losses are largely attributed to a lack of advanced infrastructure facilities or supply chain expertise, as well as fragmented and overcrowded markets, which render appropriate handling, transportation, storage and marketing of perishable commodities almost impossible. This adversely affects the price realization at the farmers' end, owing to the poor quality of produce marketed and the loss of output due to wastage. Therefore, preventing these postharvest losses will directly enhance the contribution towards national GDP.

In India, the total capacity of the cold storage units amounted to 34 million tons, which is the largest in the world, though most of the units are based on outdated, outmoded technologies, which are energy- inefficient [28]. India has to upgrade them technically, enhance their capacity, and create cold chain facilities to curtail postharvest losses. Processing and value addition can also ensure a better return to farmers.

Of all the cold storage facilities in India, controlled atmosphere storage (CAS) is the best; however, a novel type of respiratory quotient dynamic CAS (RQ-DCA) was developed to control O_2 and CO_2 partial pressures in storage containers for fruits automatically, based on RQ [29]. The fruits' firmness and skin color were better and shelf life was double that of the regular CAS. Ecozen has designed a pioneering micro solar-powered cold storage system for the rural segment that serves their needs ideally and after a two-year breakeven, lead to over 40% increase in their profits [30].

Poor supply chain management is another constraint affecting the national economy. Smart sensors or data loggers connected to GPS trackers can record real-time temperature, pressure, and humidity readings during cold chain transport. These sensors are synchronized with analytical dashboards, accessible through convenient web and mobile apps, which can alert transporters of any risk, detect the nearest service station to help navigate crises, and optimize routes to shorten delivery times.

3. Innovations for marketing aspect

Indian farmers are unable to get reasonable prices for their products even after hard work and mainly because they are exploited by the middlemen. In 2016, the Government of India launched the National Agricultural Market with a vision to e-connect markets, thereby enabling e-trading of agricultural commodities to ensure transparency in market operations, fair price discovery for the benefit of farmers, and removal of all malpractices. According to the ministry of agriculture and farmers' welfare, 3.95 million farmers, and 88,000 traders joined thee-platform, resulting in 5.9 million tons of trade across 69 commodity types worth 15,000 crore [31].

Although India is one of the largest producers of agricultural goods, it is still lagging in export to foreign countries. This is due to failure to meet the international food quality demand, as well as the pesticide residues in the consignment lots. By adopting precision agriculture, India can circumvent this problem. Agricultural and Processed Food products Export Development Authority (APEDA) implemented a residue-monitoring system for grapes in 2003, and now more residue analysis laboratories are being established near the different agricultural-export zones to detect pesticide residue before exporting the produce.

CONCLUSION

Agriculture plays a significant role in overall socio-economic development of our nation's and fostering rapid, sustained and broad-based growth in agriculture remains a key priority. It is important to ensure that innovations in science and technology encourage farmers to adopt climate smart agricultural practices through optimal utilization of natural resources, energy efficient power sources, controlling post- harvest losses through better infrastructure and marketing and improving value addition in fresh produce for better price realization for farmers. The Green Revolution using science prevented the last food crisis and currently Indian agriculture proceeding for technology-driven revolution with support from policymakers. However, we urge that the consideration of social justice should not be sidelined. Thus any revolutionary innovation should be assessed by a framework for inclusiveness, responsiveness and anticipation for making them more robust and relevant to our socio-economic conditions.

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