CHAPTER 9

Agricultural Technology for Increasing Competitiveness of Small Holders

9.1 Introduction

Agricultural technology plays a vital role in building viable and sustainable food systems. The Green Revolution (GR) is a landmark example of how scale-neutral technology transformed agricultural production, leading to increased productivity of staple grains, poverty reduction, increased availability of food grains and lower food prices (Pingali, 2012). It played an integral part in making many parts of the developing world food secure regarding calorific access and put to rest concerns of having reached the carrying capacity where the population exceeds what the agricultural sector can support. However, as India moves towards becoming the most populous nation in the world by 2050, concerns of agricultural productivity are being revisited. The limitations of GR technologies were that it was concentrated to high potential regions where irrigation was readily available, it was limited to wheat and rice and that it has had environmental consequences due to injudicious use of inputs leading to reduced soil fertility and water table depletion in some regions. In Chap. 7, we looked at the institutional factors such as land size and access to land, credit, technology and infrastructure such as irrigation that influences the ability of smallholders to commercialize and diversify. In the wake of challenges of growing population and climate change along with improving productivity and profitability, sustainability through reduced impact

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on the environment is central for the future of agricultural development. Therefore, while technology remains crucial to boosting agricultural yields and growth, newer approaches to technological interventions need to help limit environmental externalities such as land and water degradation and emission of greenhouse gases, expand to low potential areas of eastern India bypassed by the Green Revolution and bring yield increases to a more diverse group of crops.

Sustainable intensification is a process by which agricultural outputs can be increased without increasing inputs such as land, through the judicious use of agricultural inputs such as water and fertilizers and reducing externalities such as greenhouse gas (GHG) emissions and land and water degradation (Pingali, 2012; Pretty, Toulmin, & Williams, 2011). Technology or the use of scientific knowledge and management of inputs are the two main components of this approach. Technology is essential to improve yields and increase resistance to climatic risks such as droughts and floods and mechanization to reduce drudgery and improve efficiency, while management practices are necessary to improve resource utilization and reduce emissions of greenhouse gases from agricultural production. In this chapter, we highlight the significant challenges of agricultural production and the technological and input management interventions that are required to address them in the context of the Indian food system. The chapter is divided into three parts. In the first part, we look at the significant post-Green Revolution production and environmental challenges of the agricultural sector in different agro-climatic regions of the country to highlight the various challenges. In the second part, we assess the nature of technological interventions, specific to the region, that are needed to increase productivity, while limiting environmental externalities and assuring equitable growth. In this section, we look at the shift from conventional plant-breeding technologies to first- and second-generation genetically modified (GM) technologies and the promise they hold for the agricultural sector and the future of food security. Here we also look at the need for the collation and dissemination of information about the environment, economy and good practices to enable better decision making at the farm level to complement technology with effective use of scarce resources. The last part looks at the policy and institutional support that is required to enable technological interventions and adoption, especially by smallholder farmers as we look ahead to 2050.

9.2 The Post-Green Revolution Challenges to Indian Agriculture—From Environmental Externalities to Climate Change

India's grain production alone needs to grow by about 42% from the 2015 levels (or by 377 million tons) to meet the projected demand of 2050.[1] The rising demand for higher value food products such as fruits and vegetables and animal products has pressured food systems to increase yields and to diversify. The Green Revolution (GR) by tripling grain production with only a 30% increase in land under cultivation (Pingali, 2012) in the 1970s was able to offset potential shortages arising from population growth. As India moves towards becoming the most populous nation, technology is again being sought out for solutions. However, the challenges going forward are different and there is a need to develop technological interventions to address them. In this section, we look at the main challenges that sustainable intensification needs to address to emerge as a solution to boosting agricultural productivity and growth. First, we discuss the limitations of GR technologies concerning their environmental externalities and not being resource-neutral, and second we look at the challenges of climate change as a dominant variable in its influence on food production.

9.2.1 Going Beyond Green Revolution Technologies

Although GR technologies were scale-neutral allowing small farms to adopt them, they were not resource-neutral that led to sizeable regional inequality and low diversification (Chap. 7 details this discussion). Rain-fed regions, which could not adopt these technologies, did not benefit from productivity growth and development of the agricultural sector. The focus on wheat and rice led to food self-sufficiency and calorie availability, but crowding out of coarse cereals led to low micronutrient availability in the food system. The lopsided production incentives in some crops led to the emergence of intensive mono-cropping in irrigated tracts of India (Abraham & Pingali, 2019; Pingali, 2012). The environmental impact of the GR was also mixed. Although it limited conversion of new land for agriculture, excessive use of inputs led to chemical runoffs, soil degradation

[1] http://www.icrisat.org/yield-gap-and-water-productivity-atlas-launched-for-india/ (Accessed on 10/01/2018).

and water table depletion (Pingali, 2012). India has one of the world's highest rates of water depletion (Aeschbach-Hertig & Gleeson, 2012). According to the World Resources Institute, 54% of India's total area faces high water stress concentrated in the northwestern regions and the eastern coastal regions (Shiao, Maddocks, Carson, & Loizeaux, 2015), where GR technologies were most successfully adopted. Much of the eastern part of India where farm level access to irrigation is low, water stress remains low to medium.

About 64% of land degradation in India is caused by water erosion (Mythili & Goedecke, 2016), while the remaining can be attributed to human-induced and natural soil degradation resulting from deforestation, pollution, poor agricultural practices, over-grazing and wind and water erosion. Table 9.1 shows that the northwestern and southern regions have the largest degraded land area; these are also the regions with high water stress. GR technologies, therefore, came at an environmental cost and as India looks to increase yields and diversify production, it is important to consider measures to reduce environmental externalities of technological intervention and adopt technologies that may require resource use in line with regional endowments. The potential of eastern India for agricultural growth will shift the development focus to the region, and the adoption of technology along with good management practices will be necessary to reduce environmental stress and keep agricultural production sustainable.

9.2.2 Climate Change, Environmental Degradation and Production Risks

Climate change and its effect of agricultural production was not a variable considered during the GR era, but productivity growth requires higher energy utilization that inevitably leads to higher emissions. Today there is ample evidence that high emissions leading to climate change have an impact on the production conditions of crops and livestock. Agricultural production, therefore, influences and is influenced by climate change. It is a large emitter of carbon dioxide (CO_2)-based and non-CO_2-based greenhouse gases (GHGs) such as methane (CH_4) and nitrous oxide (N_2O), contributing to changes in temperature. The Indian agricultural sector contributes 18% of the total emissions of India.[2] Rice and livestock

[2] A detailed discussion on the role of climate change and food systems will be discussed in Chap. 10.

Table 9.1 Classification of land degradation in India by regions (in '000 hectares)

Region	*Water erosion*	*Wind erosion*	*Waterlogging*	*Salinity/ alkalinity*	*Several degradation types combined*	*Total degraded area*	*Area*	*Degraded area (%)*
North	23,449	9,040	4,396	3,342	335	40,562	101,061	40
Northeast	4,136	–	522	5,534	2,422	12,614	26,219	48
Central	17,883	–	359	6,842	1,126	26,210	44,345	59
East	9,249	–	3,392	2,322	194	15,157	41,833	36
West	16,446	443	599	1,869	1,993	21,350	50,743	42
South	22,330	–	5,031	1,902	1,302	30,565	63,576	48
Union territories	187	–	–	9	9	205	825	25
India	93,680 (64%)	9483 (6%)	14,299 (10%)	21,820 (15%)	7,381 (5%)	146,663 (100%)	328,602	45

Source: Mythili and Goedecke (2016)

production are the largest contributors emitting 36.9% and 38.9% of GHGs respectively by way of anaerobic and enteric fermentations (Vetter et al., 2017). Simultaneously, changing weather patterns and extreme weather events influence production conditions and the risks under which agricultural production takes place.

Yield increasing technology interventions in agriculture were also supported by policies providing input subsidies to improve and incentivize adoption. Over time, however, continued subsidization of technologies has led to their overuse. Subsidized electricity for water use made the agricultural sector energy intensive, and fertilizer subsidies made agriculture GHG intensive, especially N_2O (Vetter et al., 2017). Urea subsidies have been higher than phosphate and potash-based fertilizers, and this has led to over-application of nitrogenous fertilizers resulting in lower efficiency and soil health (Prasad, 2009). Subsidized electricity has also shown to lead to over irrigation, severely depleting groundwater levels (Bhanja et al., 2017; Jacoby, 2017; Raman et al., 2015). Agricultural practices such as excessive tillage and overuse of machinery, heavy use of inorganic fertilizers, poor irrigation and water management techniques, pesticide overuse, low carbon inputs, and reduced crop cycle planning are significant contributors to degradation (R. Bhattacharyya et al., 2015).

The effects of climate change from temperature increase and land and water degradation will have different effects in various agro-ecological regions. In marginal areas constrained by water-related challenges, the impact of droughts and water shortages will have a significant impact on productivity through increased agro-climatic risks. In high agricultural productivity areas, water shortages due to depleting groundwater levels, water contamination due to runoffs and soil degradation due to over-application of fertilizers will be detrimental to production. Diversification to higher value agriculture may also require higher inputs in the form of water, fertilizer and feed, and with it will come increased emissions. Technology interventions, therefore, have the twin task of improving productivity while reducing and managing externalities. However, technology interventions come at an energy cost (Soby, 2013), and as agricultural production moves towards higher commercialization, emissions are bound to increase. Coupling technology with good management practices to reduce externalities, efficiently utilize water and land resources and chemical and fuel inputs are essential to mitigate climate change and reduce its impact on agriculture.

9.3 The New Role of Technology and Management for Sustainable Agriculture

The biggest technological challenge in agriculture is to increase yields through intensification, without increasing negative externalities of diminishing biodiversity, greenhouse emissions and land and water degradation, among others—this is often referred to as sustainable agricultural intensification (FAO, 2016; Matson, Parton, Power, & Swift, 1997; Pretty et al., 2011). With a majority of production taking place on small and marginal farms, making technology accessible is crucial for income growth, poverty reduction, food security, gender empowerment and environmental sustainability (Byerlee, de Janvry, & Sadoulet, 2009; Pingali, 2010). However, the limited capacity of smallholders to manage climatic risks, especially during adverse events is limited, and this can trap them in chronic poverty (Carter & Barrett, 2006; Fafchamps, 2003; Kebede, 1992).

Technology, therefore, needs to focus on three aspects: One, technology needs to be accessible by often resource-poor small and marginal producers. Two, it should help increase productivity for a growing population keeping in mind limitations of land and water resource availability. Three, technology should enable and better manage resource utilization and externalities from agricultural production to prevent accentuation of climate change. The impacts of climate change will be felt disproportionately across India with sub-humid and semi-arid regions prone to droughts, the delta and coastal regions prone to flooding and storms. Strategies tailored to regions depending on current agricultural development and climatic risks are essential to address specific risks. In this section, we look at the role of plant technology interventions in increasing production and management practices that make up the core of sustainable intensification and technology approaches to improve efficiency in the context of Indian agriculture. We specifically look at the increasingly important role of biotechnology in the form of genetic modification supplementing GR technologies that were predominantly based on conventional plant-breeding (CBP).

9.3.1 Yield Gaps and Resilience—The Role of Plant Technologies

India has 20 agro-ecological zones (AEZs)[3] with varying physiography, precipitation, temperature and soil type determining conditions under which agricultural production takes place (L. Ahmad, Habib, Parvaze, &

[3] This classification is used by the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP). These 20 AEZs are further divided into 60 sub-zones.

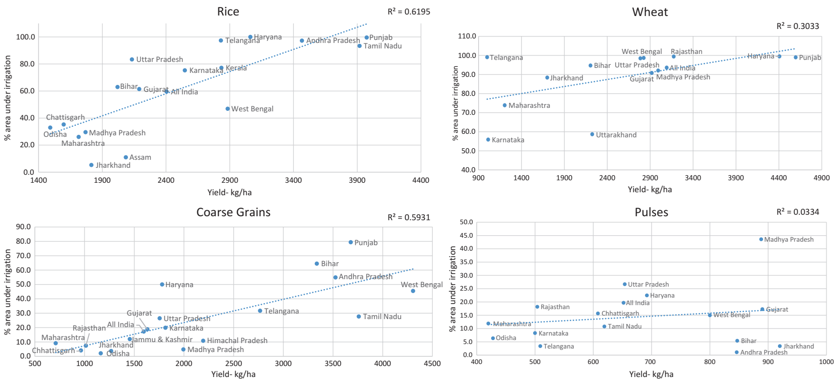

Fig. 9.1 Relationship between yield and area under irrigation in selected crops in India (2015–16). Source: Department of Agriculture, Cooperation & Farmers Welfare, Government of India; based on authors calculations

Sheraz, 2017). In the sub-humid and semi-arid regions of central and the eastern parts of the country, agro-climatic risks and availability of water are significant challenges to agricultural production. Ninety-four percent of wheat production and 95% of sugar production takes place under irrigated conditions. Sixty percent of the area under rice is irrigated while less than 10% of coarse grains and 20% of pulses are grown under irrigated conditions. Figure 9.1 shows the relationship between yield and irrigation in various states for rice, wheat and coarse grains. In the case of rice, wheat and coarse grains, there is a strong relationship between yields and irrigation, with states with higher access to irrigation having higher yields. In pulses, this relationship does not hold as the average yield in Jharkhand and Madhya Pradesh is the same despite a 40% difference in access to irrigation for pulses cultivation.

In Punjab, the wheat yields are 2 to 2.4 times higher than in other states, and rice yields are 1.5 to 2 times that of states such as Odisha, Maharashtra, Madhya Pradesh and Bihar. Increasing production of major staples sustainably would mean closing this yield gap between regions. Figure 9.2 also shows differences levels of irrigation within a state for different crops. While close to 90% of wheat cultivation in Madhya Pradesh is under irrigation, less than 10% of coarse grains come under irrigated conditions. In coarse grains such as millets and sorghum and pulses, the Indian yields are low in

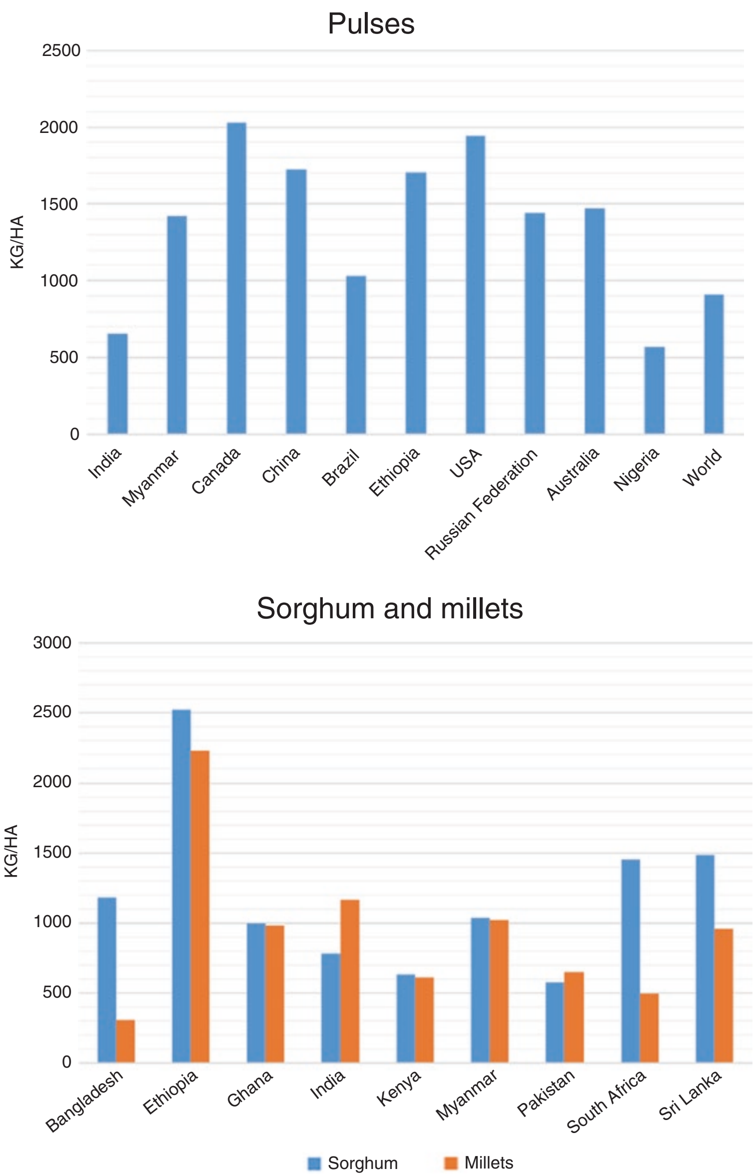

Fig. 9.2 Global variations in yield. Source: FAOSTAT; based on authors calculations

comparison to other developing countries (Fig. 9.2). Low level of R&D and limited access to irrigation for coarse grains and pulses restricts the availability of marketable surplus and increases risks of production, disincentivizing production. Increasing the yield of pulses will incentivize their adoption in the fallows of eastern India helping improve availability and incomes. Higher yields from pulses that are grown mostly in regions where access to irrigation is low will enable income growths and incentivize production. Increasing coarse grain yields and breeding more climate resilient varieties will enable its adoption more widely.

Evidence of climate change affecting agriculture is strong. The challenges agricultural production faces from temperature increases are decreased yields (Lobell, Schlenker, & Costa-Roberts, 2011; Nelson, Valin, et al., 2014), higher risks of pest attacks and disease outbreaks (O'Brien et al., 2004), lower quality and quantity of feed and forage and water availability depletion. These changes would not only affect the production of crops, but also impact the production of livestock and complementary products such as milk availability (Rojas-Downing, Nejadhashemi, Harrigan, & Woznicki, 2017). Also, heat stress impacts animal health, increases parasites and pathogens (Niang et al., 2014; Thornton, van de Steeg, Notenbaert, & Herrero, 2009) and increases the risk of mycotoxin contamination in cereals and pulses (Paterson & Lima, 2010). The latter increases safety concerns in the food supply chains as products move from farm to plate. Closing existing yield gaps and regional disparities in agricultural production, while simultaneously dealing with concerns of climate change, will be the significant aim and challenge of technological interventions as we look ahead.

Although the role of conventional plant-breeding to improve yields in coarse grains and pulses remain significant, genetic engineering advances have led to opportunities in developing plants that can improve yields, remain resilient to climate change impacts and also reduce environmental externalities. Genetically modified organisms (GMOs) can be more precise, productive and faster than conventional plant-breeding (CPB) and have found use in biofuels, food, cash and fodder crops, livestock, fisheries and forestry. The primary difference between GM biotechnology and CPB is that biotechnology transcends species and uses gene manipulation, gene transfer between species, DNA typing and cloning to develop new plant varieties (C. N. Rao, Pray, & Herring, 2018). The first-generation of GM crops was engineered to have tolerance or resistance to insects, pesticides and herbicides, and examples of these were Bt maize, Bt cotton, Pat-maize and GT soybeans, among others. In India, Bt cotton was the only first-generation GMO that was introduced to the agricultural sector. Second-generation GMOs are characterized by increased tolerance to abiotic stress (drought, flood salinity) and substantial changes in content of nutrients (protein, amino acids, fatty acids, starch, vitamins, minerals and enzymes), enabling the creation of resilient and more nutritive crops (Buiatti, Christou, & Pastore, 2013; Flachowsky & Aulrich, 2001; C. N. Rao et al., 2018). So far, no second-generation GMOs have been allowed in the Indian agricultural sector.

Enabling yield increases in coarse grains such as millets and sorghum and pulses and developing crop varieties specific to sub-humid and semi-arid agro-ecologies will be the role of technology in production increase. R&D through CPB to introduce high-yielding varieties (HYVs) of coarse grains and pulses will help productivity growth in regions of eastern India where they have an advantage in growing, enabling income growths and increasing per capita availability of these crops that have been decreasing over the past few decades. Adoption and growth of Bt cotton production in India is an example of a first-generation GMO that has been widely adopted and has had a significant impact on pesticide reduction, yield gains and income increase contributing to poverty reduction and rural development (Qaim, Subramanian, Naik, & Zilberman, 2006; A. Subramanian & Qaim, 2011). Bt cotton, a genetically modified organism (GMO) using *Bacillus thuringiensis*, a naturally occurring bacterium that protects from bollworm infestation, was first introduced in India in 2002. Since then, cotton yields have gone up almost four times and the total cotton production increased from 11.53 million tons in 1999–2000 to 32.58 million tons (Fig. 9.3).

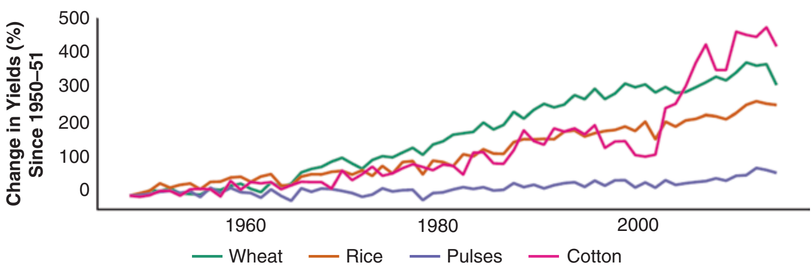

Fig. 9.3 Yield trends in selected crops in India from 1950–51 to 2016–17. Source: Department of Agriculture, Cooperation & Farmers Welfare, Government of India; based on authors calculations

Due to the reduced use of pesticides, it has been found that the environmental impact quotient of Bt cotton was lower than conventional cotton breeds (Ashok, Uma, Prahadeeswaran, & Jeyanthi, 2018).

In the wake of climate change, development of second-generation GMOs that can withstand agro-climatic risks is essential. Development of heat-tolerant and drought-resistant crops will allow for productivity growth in regions that were bypassed by the Green Revolution and in temperate regions susceptible to weather-related risks. Drought tolerant varieties in staples such as maize, rice and wheat have been in development and are in various stages of implementation or trials. The International Maize and Wheat Improvement Center (CIMMYT) and the International Rice Research Institute (IRRI) have been front-runners in this research. Research on developing heat-resistant wheat, rice and maize are still ongoing, and they are not yet commercially available (Rosegrant et al., 2014). Like drought resistance, heat resistance in a plant is an essential trait in the wake of climate change. In the semi-arid regions, this may prove crucial for agricultural production. Chapter 10 discusses the effects of climate change on the nutritive value of crops as there is ample lab-based evidence to show that rising temperatures can reduce the nutrient contents such as proteins and vitamins in crops. GMOs allow for the biofortification of crops that would increase nutrient content, compensating for reduced availability.

Technology to reduce emissions from growing various crops is also important. Plants with traits such as Biological Nitrification Inhibition (BNI) that suppresses the loss of nitrogen from the soil can improve uptake efficiency and boost crop productivity (Subbarao et al., 2017). These technologies coupled with management practices such as zero tillage can reduce emissions significantly. The IMPACT models of the International Food Policy Research Institute (IFPRI) that assesses the long terms challenges in addressing hunger and poverty forecasts that the number of undernourished people can be reduced by 12% or 124 million in developing countries through nitrogen-efficient crops. Further, the model also predicts that 9% or 91 million and 8% or 80 million of the worlds under nourished can be reduced though adopting zero tillage and heat tolerant and precision agriculture methods respectively (FAO, 2016; Rosegrant et al., 2014). These changes might be significant in the Indian agricultural sector. Technological intervention, however, needs to be coupled with management practices for efficient implementation and reducing environmental externalities as witnessed under the Green Revolution.

9.3.2 Information, Management Practices, Production and Consumption Efficiency for Sustainable Intensification

The accessibility and availability of information are crucial to making agricultural production and marketing decisions needed for agricultural growth and development. As farms increase their engagement with markets, information systems are essential to enable them to make proper planting, harvest and marketing decisions (Aker, 2011; Ogutu, Okello, & Otieno, 2014). Information communication technologies (ICTs) have been shown to have great potential in reducing information asymmetries and improving the efficiency of production and marketing. Management of resources, especially inputs, is essential to bring about sustainable intensification. Technological measures to increase productivity need to be coupled with management of resources to reduce externalities such as emissions and overuse of natural resources. Management practices in agriculture and availability of information are inextricably linked as one complements the other. In this section, we look at the importance of improving access to information, the role technology plays in enabling this and how information access and good management practices go hand in hand.

ICTs are any medium or device that allows for the collation and dissemination of information. The advantages of ICTs are that they can enable quick dissemination of accurate information in an information-intensive activity like agriculture. Table 9.2 shows the different stages of production and the nature of the information that is essential to make significant production and marketing decisions. The major types of information and services producers require are market and price information, weather information, technical extension services-based information or the combination of the three (Aker, Ghosh, & Burrell, 2016). The traditional ICTs were the television, radio and newspapers, and in the last decade or so, mobile phones have emerged to be the dominant medium. Between 2003 and 2016, the number of mobile phones grew at a CAGR of 40% from 13.29 million to 1027 million. Mobile phone penetration and easy access to data plans make ICTs more effective in making information accessible. There is evidence to show that ICTs can play a role in the early adoption of technologies such as GM crops and practices such as zero tillage (Fischer, Byerlee, & Edmeades, 2009). Studies have also shown that ICTs help in acquiring information about

Table 9.2 Stages of production and marketing and type and source of information

Stages	*Information*	*Source*
Pre-cultivation	Crop selection	Input and output market, technical extension and meteorological
	Land selection	Input market
	Commodity price	Output market
	Weather	Meteorological
Cultivation	Land preparation	Technical extension
	Access to credit	Financial
	Access to inputs	Input market
	Planting	Technical extension
	Weather	Meteorological
	Water, fertilizer, pest management	Technical extension
	Labor	Labor market
Harvest	Labor	Labor market
	Mechanization	Technical extension
Post-harvest	Processing	Output market
	Storage	Output market
	Transportation	Output market
	Marketing	Output market
	Commodity price	Output market
	Grades and standards/quality	Output market

Source: Adapted from Aker et al. (2016)

seed varieties, weather-related information and diseases (S. Mittal & Mehar, 2012) and better price realization and less wastage (Aker & Fafchamps, 2015; Muto & Yamano, 2009; J. Robert, 2007).

ICTs often rely on platforms on which information can be collated. These platforms would bring together information regarding weather, technical extension and markets. Creating and maintaining these platforms can be costly. Information platforms need to have a sufficient user strength and a steady revenue stream in order to be financially viable. Information also needs to be reliable, accessible and affordable for it to have an impact on agricultural production and marketing.

Management of resources that goes into agricultural production needs to complement technology adoption for sustainable intensification and reduced environmental externalities. The FAO (2010) describes conservation agriculture (CA) technologies as resource-saving agricultural practices that consider sustainable productivity and profits in enabling conservation. Climate-smart agriculture as "agriculture that sustainably increases productivity enhances resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals" (FAO, 2010; Lipper et al., 2014). Supplementing agricultural programs with agroforestry for carbon sequestering, soil conservation and watershed management programs is crucial for sustainable intensification (Lipper, Pingali, & Zurek, 2006; Pretty et al., 2011).

As soils hold the second largest pool of carbon (after the oceans), changes in the stock of organic carbon in them can affect atmospheric CO_2 to a great extent (Chappell, Baldock, & Sanderman, 2015). The type of soil, nutrient and water management practices adopted by farmers during agricultural production influences these cycles. Maintaining the balances in the carbon and nitrogen cycles plays a vital role in the reduction of GHGs and is an integral part of soil management (J. A. Burney, Davis, & Lobell, 2010; Wollenberg et al., 2016). In India, the use of nitrogenous fertilizers (urea) is disproportionately higher than phosphate and potash due to high subsidies, and the use varies from state to state. In irrigated tracts application rates are much higher, and in states like Punjab, Haryana and Telangana, urea use ranges between 169 and 185 kg/hectare, while in Madhya Pradesh, Rajasthan and Odisha, the application rates range between 24 and 53 kg/hectare. The amount of fertilizer applied to the soil, fallowing practices, nitrogen-fixing crop cover and tilling practices are the main determinants of these cycles and the amount of CO_2 and N_2O released into the atmosphere. Judicious use of nitrogen fertilizers and fallowing and tilling practices are critical to limiting N_2O emissions and prevent soil erosion and loss of organic matter from the soil. Also, integrated soil fertility management (ISFM) that involves balancing organic and synthetic fertilizer to maintain a balanced supply of nutrients and good land management practices need to be put in place to ensure the sustainable increase of yields.

Increasing water use efficiency is essential to ensure the availability of water and mitigate the effects of prolonged drought scenarios. This requires an institutional and technical change at the farm and national level that enables conservation, replenishment and effective allocation. In rain-fed regions of the country, investment in irrigation infrastructure, especially drip irrigation, and promotion of activities such as water harvesting will be critical to improving water availability. Water stress and drought are often exacerbated by land degradation in sub-humid and semi-arid conditions to a higher degree than purely arid conditions (Adhikari, 2013). The sensitivity of a particular food system to climate change increases with scarcity and degradation of these natural resources. Therefore, systems by which resources are used and replenished will help manage the impact of agricultural production on the environment. Watershed and aquifer management in semi-arid regions along with informational services on climatic variability need to be built into water management practices to help regions cope or manage water stresses.

Effective management of common-pool resources is critical to conservation agriculture, and this cannot be done without community-based initiatives that disseminate and implement location-specific interventions in different agro-climatic zones. Conservation and climate-smart agriculture are methods of sustainable intervention that works in tandem with technological intervention. Extension services to improve agronomic practices, infrastructure and access to technology are essential interventions for smallholders. However, institutional interventions are required to enable adaptation by small farms.

9.4 The Way Forward: Institutional Support for Technology Adoption

The role of the state and institutions in areas such as biotech policies, infrastructure and credit systems that can improve smallholder access to technology is critical to enable sustainable intensification. The successful diffusion of GR technologies was a result of scale-neutrality of technologies and state and policy support. State involvement resulted in subsidies for inputs and their effective distribution along with extension services at the production stages and assured prices and procurement by the state to create buffers incentivized their adoption in a big way (Pingali, 2012). The Indian Council of Agricultural Research (ICAR) and the State Agricultural Universities (SAUs) adapted the technology that came from the International Maize and Wheat Improvement Center (CIMMYT) and the International Rice Research Institute (IRRI) for Indian conditions. The National Chemical Laboratory in Pune helped with developing efficient methods for pesticide production, the Projects and Development India Ltd. (PDIL) designed and built fertilizer factories and the Central Mechanical Engineering Research Institute (CMERI) was instrumental in designing the economic Swaraj tractors (Pray & Nagarajan, 2014).

The fundamental platform of GR technology was hybrid seeds through conventional plant-breeding that could improve the yield of crops. Since GR, there has been a significant paradigm shift in agricultural R&D, and newer agricultural technological interventions that have emerged are based on genetic modification, relying on changing the fundamental traits of plants (Ramani & Thutupalli, 2015). This brings to the forefront three concerns of affordability, adaptability and safety. Newer technologies may require a higher amount of capital, expertise and infrastructure to be accessed and implemented. For mechanization of farms the issues of economies of scale and with reference to GM technologies, issues of public health and safety need to be addressed. Institutional intervention such as improved access to credit, smallholder aggregation and platforms for debate and deliberation regarding GMOs need to evolve.

9.4.1 Cost of Technology—Affordability, Adaptability and Economies of Scale

In the last decade, funds for public sector R&D have reduced globally and private sector involvement in this space has been growing (Jaruzelski, Staack, & Johnson, 2017). In the case of China, India and Brazil, however, public sector investments have been increasing, although not at the pace of private sector investments. Significant investments are being made in seed and plant biotechnology, agricultural machinery, pesticides and fertilizers (Pray & Nagarajan, 2014). In India, the public sector is a significant player in R&D with regard to self-pollinated crops such as rice, wheat, pulses and oilseeds (Ferroni & Zhou, 2017). The public sector has a 50% share in fertilizer and 20% share in seed production and sales. As the majority of seed production and sale and mechanization and pesticides take place through the private sector, it has come to play a significant role in agricultural inputs since the 1980s. At the same time, public sector R&D under the ambit of the ICAR has been under considerable stress due to lack of financial resource, research clarity and collaboration between different public research institutions (GOI, 2015).

Smallholder access to seed technologies, mechanization, information and extension services will determine their ability to be economically viable and sustainable. Traditionally the state has played an enabling role in agricultural production as policies and R&D institutions have determined smallholder access to credit, information and extension services, subsidies and price support. These measures favored the major staple grains such as wheat and rice, incentivizing their widespread adoption at the cost of other crops such as pulses and coarse grains. Leveling the policy playing field by removing distorted support and improving marketing infrastructure can encourage the emergence of R&D in other crops such as coarse grains and pulses and enable diversification. The state support and encouragement in the formation of community-based development programs such as water user groups, agroforestry and aggregation models are needed and essential to enable smallholders to better adapt and implement newer interventions for conservation agriculture and to rectify economies of scale disadvantages.

The role of aggregation models in smallholder agricultural systems like India is vital in accessing credit and mechanization. This is discussed in more detail in Chap. 7. Mechanization is emerging to be an essential aspect of production, especially concerning rising farm and non-farm wages. It plays a crucial role in improving the efficiency of labor by reducing drudgery, time savings (Ibarrola-Rivas, Kastner, & Nonhebel, 2016) and also improving the nutritional status of individuals by diversifying household level time use (D. Johnston, Stevano, Malapit, Hull, & Kadiyala, 2018). Women face significant labor productivity constraints, and often conservation agriculture may increase women's workload (from weeding and other labor-intensive activities) and reduce the burden on men (Kaczan, Arslan, & Lipper, 2013). Rental market for farm machinery is a fast growing service (Binswanger & Singh, 2017), and women's self-help groups (SHGs) jointly owning and leasing out machines are successful models that can be seen in many locations. Therefore, productivity-enhancing technologies and interventions need to be gender-neutral and in some cases gender-specific (Carrand & Hartl, 2010). The policy challenge we highlight here is how to promote (a) context-specific, (b) environmentally sustainable, (c) affordable and (d) gender-neutral technologies.

9.4.2 The GM Debate

Genetic modification entails the creation of crops with desired characteristics such as herbicide tolerance, disease and pest tolerance, quality improvements, reduced emissions, tolerance to biotic stress and quality enhancements (Nelson, 2001). The process often involves moving genes between (sexually incompatible) organisms to create 'transgenic' crop species that can be conducive to resilient agricultural development. In the wake of climate change, natural resource degradation and the need to increase food production, the potential of biotechnology is promising. However, the longer-term side effects of technology can seldom be predicted with accuracy. Even with GR technologies, externalities such as environmental degradation and erosion of biodiversity, among others, emerged only later, making GMO a contentious topic in India as around the world. Despite no verifiable evidence of adverse effects on the environment, human or animal health, there has been a strong opposition to GM technology in India (C. N. Rao et al., 2018). Bt cotton, the only GM crop allowed in India, is a cash crop, and the lines of the debate were soft. However, resistance by civil society to introducing GM crops for human consumption has been influential within India. Although the biosafety regulatory mechanism in India is robust with every organization involved with recombinant DNA research requiring Institutional Biosafety Committees (IBSCs) and having the Department of Biotechnology under the Ministry of Science approving any new technology, the debate on GM crops is still polarizing.

The existing and future challenges of the Indian and global agricultural systems to increase production and adapt to climate change require technological interventions in both the first- and second-generation GM crops. As discussed earlier in this chapter, the impact of Bt cotton on incomes and the environment in India have been positive as a result of lower cost of production from reduced pesticide use and higher yields. In 2009, an attempt to introduce Bt brinjal in India failed due to pressure from civil society organizations despite being approved by the Genetic Engineering Approval Committee (GEAC) under the Ministry of Science (Herring, 2015). The government has since introduced a moratorium on GMOs until sufficient evidence proved they were safe. In 2014, the government proclaimed GM crops to be in the national interest which approved further field trials for GM rice, mustard, cotton, chickpea and brinjal (Ramani & Thutupalli, 2015). Categorization of GM as a special risk has created an uncertain investment climate that has driven out small players in the biotechnology sector (C. N. Rao et al., 2018).

The NITI Aayog in the Economic Survey of 2015–16 came out in favor of GMOs and in the years to come India can expect a shift to GMOs in food crops. However, there are significant issues that still need to be addressed regarding trust in regulatory mechanisms, platforms for dialogue and information dissemination and reporting. With the deviation from the state being the center of R&D in agriculture, its approaches to regulating biotechnology to assure biosafety are essential. Central to this regulation is building trust in these institutional processes. For this, in India, there is a need for platforms for debate between science communities, civil societies, farmers groups, state and citizens. Misinformation and inadequate translation of scientific research impact on society can often skew or polarize debates of such kind. The need to promote translation services to inform debates is also vital as we move ahead. Effective platforms of addressing such concerns are central to encourage R&D and innovations especially in the private sector that can address specific problems related to crop yield, resilience and quality to meet the food security challenges of the future.

9.5 Conclusion

Technology in the past has played a critical role in enabling food security in the developing world. The Green Revolution helped in increasing yields of wheat and rice, making many countries like India self-sufficient in these grains. One main reason the Green Revolution was successfully implemented was that it was scale-neutral, allowing small and marginal producers to adopt them. However, as these technologies were not resource-neutral, only regions with access to irrigation and rainfall were able to adopt them. The limitation of these technologies was that they were limited to significant staple grains and in regions where irrigation resources were available, leading to inter-regional and intercrop disparities. The impact these technologies had on the environment because of poor management was also high, leading to depletion of water tables and land degradation.

Technology remains critical for the new food security challenges India will face as we move towards becoming the most populous country in the world. Adding to production challenges is the issue of climate change. As agriculture influences and is influenced by climate change, the need to reduce emissions and other environmental externalities as the sector grows become essential. Therefore, the new role of technology is sustainable intensification—or increasing productivity by limiting or reducing externalities such as land and water degradation and emissions. First- and second-generation GM technologies hold promise in improving returns to farming through reduced cost of production and increasing resilience and the nutritive value of crops in the wake of global warming and climate change. Coupled with the effective management of resources (nutrient, water, natural resources) to improve efficiency and reduce their overuse is necessary in India.

However, assuring access and availability of technology to smallholders is vital to ensure sustainable intensification. Unlike Green Revolution technologies, newer technologies are private goods, and access to capital and scale to implement are essential. Institutional interventions to promote aggregation models and improve access to credit are essential to enable adoption by smallholders. There has been much debate about the safety of GM crops in India and around the world. Despite no evidence being found that GMOs are detrimental to human, animal and environmental health there has been much opposition to it, discouraging investments and innovation in agricultural R&D. India needs to have more forward-looking biotechnology policies and institutions that can address some of the concerns regarding the safety of GMOs and lay to rest misinformation. This is essential to bolster innovation and investment from the private sector and also enable institutional support for the adoption of biotechnology in agriculture.

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