Part I
Climate Change and Abiotic Stress Factors

Improving Crop Productivity in Sustainable Agriculture, First Edition.
Edited by Narendra Tuteja, Sarvajeet Singh Gill, and Renu Tuteja.

1
Climate Change and Food Security

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Abstract

The Green Revolution ushered in the 1960s brought unprecedented transformation in agricultural production, productivity, food security, and poverty reduction. But, it has now waned. The numbers of hungry, undernourished, and poor remain stubbornly high. Moreover, the natural agricultural production resources, particularly water and land, have shrunk and degraded. The problem has further exacerbated by the global climate change and extreme weather fluctuations widely depressing agricultural yields, increasing production instability, and degrading natural resources. If the change is not managed adequately, the agricultural yields will drop by up to 20% by the year 2050 and the national GDP will erode annually at least by 1%. A series of adaptation and mitigation pathways involving business unusual have been suggested toward developing climate smart agriculture by increasing agricultural resilience to climate change through integrating technology, policy, investment, and institutions with special reference to the resource poor, women, and other more vulnerable people.

1.1
Background and Introduction

Toward the year 2050, the world population is projected to stabilize at around 9.2 billion. In order to adequately feed this population, the global agriculture must double its food production, and farm productivity would need to increase by 1.8% each year – indeed a tall order. On the other hand, the natural resources – the agricultural production base, especially land, water, and biodiversity – are fast shrinking and degrading. For instance, by 2025, 30% of crop production will be at risk due to the declining water availability. Thus, in order to meet the ever-intensifying demand for food and primary production, more and more is to be produced from less and less of the finite natural and nonrenewable resources.

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The challenges of attaining sustainably accelerated and inclusive growth and comprehensive food security have been exacerbated by the global climate change and extreme weather fluctuations. The global warming due to rising concentration of greenhouse gases (GHGs) causing higher temperature, disturbed rainfall pattern causing frequent drought and flood, sea level rise, and so on is already adversely impacting productivity and stability of production, resulting in increased vulnerability, especially of the hungry and resource-poor farmers, and is a growing threat to agricultural yields and food security. World Bank projects that the climate change will depress crop yields by 20% or more by the year 2050. Livestock and fish production will likewise be impacted. Pathogen virulence, disease incidences, pest infestations, epidemic breakouts, and biotic stresses in general are predicted to intensify.

The impact of the climate change will vary across ecogeographic and demographic domains. As projected, the bulk of the population increase will materialize in developing countries. Most of these are agriculture based, and several of them are food deficit. Moreover, these countries have high concentration of smallholder resource-poor farmers and their agriculture is predominantly rainfed, which is inherently low yielding and vulnerable to weather fluctuations. In such countries, sustained and accelerated agricultural growth is fundamental not only to achieving food security but also to generating economic growth and opportunity for overall livelihood security.

India will be the most populous country in the world by 2050, with a projected population of over 1.5 billion, and will need to double its food production by then to ensure its food security. The country was able to overcome its food crisis and insecurity through ushering in the Green Revolution in the mid-1960s. Between 1965 and 1995, the food and agriculture production and productivity had more than doubled and the intensity of hunger and poverty had halved [1]. This revolution was largely due to the synergy of technology, policies, services, farmers' enthusiasm, and strong political will. However, the Green Revolution has now waned. During the past decade or so, while the overall national GDP had registered a high growth rate of 7–9%, the agricultural growth had gone sluggish (although recovered lately).

Unethical as it is, the country is still home to almost one-fourth of the world's hungry and poor, and over 40% of our children are undernourished. The income gap between farmers and nonfarmers has widened rather unacceptably, farmers' income being about one-fifth of that of the nonfarmers (Figure 1.1). This is primarily due to the steadily declining share of agriculture in GDP while the intensity of dependence on agriculture for livelihoods has remained high. The agriculture's share in GDP fell from about 35% in 1980 to 15% in 2010, and is expected to fall to 5% in 2040 (Figure 1.2), whereas in 2010 over 50% of the population was dependent primarily on agriculture.

In an agriculturally important country like ours, agriculture is the main driver of agrarian prosperity and comprehensive food and nutritional security. The past Five-Year Plans have been aiming at an agricultural growth rate of 4% and above to achieve a balanced overall GDP growth rate of about 8–9%. But, we have not been able to achieve the targeted growth in the agricultural sector, being 3.3% during

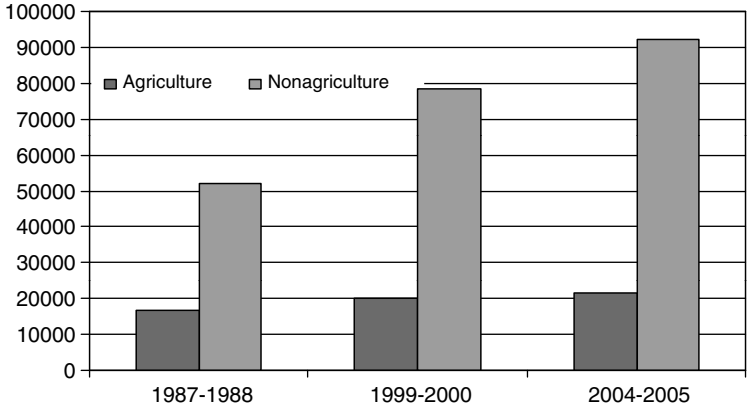

Figure 1.1 Per worker GDP in agriculture and nonagriculture sectors, Rs. at 1999–2000 prices. (*Source*: Ref. [2].)

1980–2010 and only 2.3% during the decade ending 2010. The coefficient of variation (CV) of the agricultural growth has been high and, if not managed, will further increase with the increasing volatilities caused due to climate change. The XII Plan also targets an overall agricultural output growth of 4.0–4.5% coupled with inclusiveness and gender sensitivity. A business unusual rooted in the principles of ecology, environment, economics, and equity is called for ensuring sustained and enhanced livelihood security of our people in face of the fast changing climate.

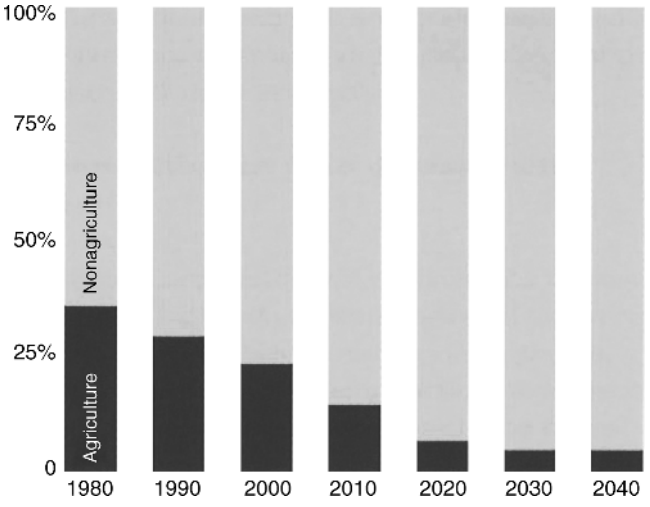

Figure 1.2 Agriculture's share in GDP steadily declining. (*Source*: Refs [3, 4].)

1.2 State of Food Security

The number of undernourished people in the world had been increasing for a decade or so and the number of hungry for the first time had crossed the 1 billion mark in 2008–2009 [2], but the number came down to 925 million in 2009–2010. Nearly all hungry people were from developing countries. The gains made in the 1980s and early 1990s in reducing chronic hunger have been lost and the hunger reduction targets of the Millennium Development Goal 1 (MDG1) as well as of the World Food Summit (WFS) remain elusive. The soaring food prices of 2007–2008 had drawn the poor farther from food, resulting in the unusual increase in the number and even proportion of undernourished. Despite the fall in international food and fuel prices starting in the late 2008, the prices in domestic markets remained 15–25% higher in real terms than the trend level – continuing the distress for the poor. High food inflations and the associated household food security have been recurrent features in India.

The continued neglect of agriculture during the past decades had denied hundreds of millions of people access to adequate food and has kept them below the poverty line. Globally, as also in India, the hunger and poverty incidences are mirror images (Table 1.1) and cause and consequence of each other. The rapid increase in the number of hungry and poor in the recent years reveals that food, fuel, and economic crises arise from the fragility of present food systems and livelihood security programs. Necessary structural adjustment and macroeconomic stabilization policies should be designed to minimize the impact of the shocks, particularly through enhanced investment in agriculture (including nonfarm rural activities and employment), expanding safety nets and social assistance programs, and, of course, improving governance.

In India, as mentioned earlier, the Green Revolution had transformed the country from the status of a food-deficit country to a food self-sufficient nation (at macro level). Per caput dietary energy supply (DES) increased from 2370 kcal/day in 1990–1992 to 2440 kcal/day in 2001–2003, and prevalence of undernourishment in total population decreased correspondingly from 25 to 20%. Between 1993/1994 and 1999/2000, 58 million individuals came out of the poverty trap, the number of poor dropping from 317 million to 259 million. Other livelihood indicators such as literacy rate and longevity also increased significantly. Life expectancy at birth in

Table 1.1 Poverty ($1.25 a day or less) and hunger levels in the developing world.

Region	% Poverty	% Hunger (undernourished)
Asia-Pacific	27	17
Latin America and Caribbean	8	10
Sub-Saharan Africa	51	32
Total developing countries	29	20

Source: Ref. [5].

Table 1.2 Number and percentage of undernourished people in India since the base year 1990–1992.

Year	Total population (million)	Undernourishment	
		Number (million)	Percent
1990–1992	863	215	25
1995–1997	949	202	21
2001–2003	1050	212	20
2005–2007	1116	221	20
2009–2010	1168	245 (est.)	21

Source: Refs [3, 5].

2005/2006 was over 63 and 66 years, respectively, for males and females against 58 and 59 years in 1986–1991 [3].

Despite India's national level food self-sufficiency and security, the number of food insecure people in India has remained stubbornly high, in recent years hovering around 245 million, one-fourth of the world's food insecure people. In fact, during 2007–2010, the number of hungry in the country, as in the world as a whole, had increased due to soaring food prices. In percentage term, however, food insecurity in India had reduced from 25% in 1990–1992 to 20% in 2001–2003, but in recent years has increased to 21% (Table 1.2). The record food grain production of over 230, 240, and 250 million tons during the years 2009–2010, 2010–2011, and 2011–2012, respectively, should have improved the situation, which should be known from the latest household survey reports. In any case, one-fifth to one-fourth of our people are still hungry and poor.

The above situation is ascribed primarily to the high and increasing population pressure (nearly 16 million being added annually to the already 1.20 billion population) and to the distributional and economic access problems, aggravating the household and individual level food insecurities. Obviously, India has made little progress toward WFS and MDG targets, whereas China and Brazil are fairly close to achieving the targets. India must critically analyze the situation and take necessary measures to get on the track to meet the targets, as done by Brazil and China.

The Global Hunger Index (GHI), which incorporates three interlinked hunger-related indicators – the proportion of undernourished in the population, the prevalence of underweight in children, and the mortality rate of children, worldwide improved from 19.8% in 1990 to 15.1% in 2010. The higher GHI was for South Asia at 22.9. In 2010, among the 84 countries (for which data could be available) having GHI above 5.0 (ranging from 5.2% in Syrian Arab Republic to 41.0% in Democratic Republic of the Congo), India with GHI at 24.1 ranked 67. This alarming GHI in India was driven by high levels of child underweight (Table 1.3). Unfortunately, over 40% of the undernourished children of the world have their homes in India (Figure 1.3). Thus, in order to improve the GHI score, India must

Table 1.3 Contributions of the three components of GHI and the underlying data for calculating the 1990 and 2010 GHI in India and in its major neighboring countries.

Country	Proportion of undernourished in the population (%)		Prevalence of underweight in children under 5 years (%)		Under 5 mortality rate (%)		GHI	
							With data from 1988 to 1992	With data from 2003 to 2008
	1990–1992	2004–2006	1990–1992	2003–2008	1990	2008	1990	2010
India	24.0	22.0	59.5	43.5	11.6	6.9	31.7	24.1
Bangladesh	36.0	26.0	56.5	41.3	14.9	5.4	35.8	24.2
China	15.0	10.0	15.3	6.0	4.6	2.1	11.6	6.0
Pakistan	22.0	23.0	39.0	25.3	13.0	8.9	24.7	19.1
World	—	—	—	—	—	—	19.8	15.1

Source: Ref. [6].

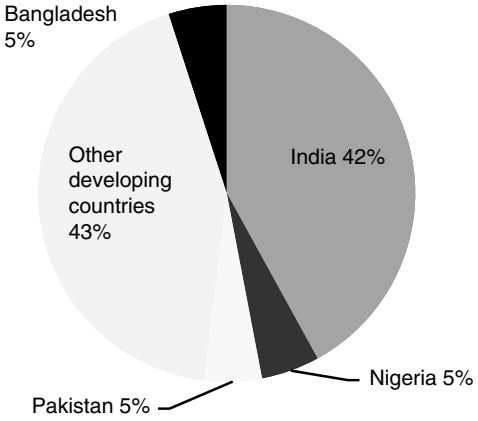

Figure 1.3 Share of underweight children under 5 years of age. (*Source*: Ref. [7].)

accelerate progress in reducing child underweight by improving childhood nutrition. Seasonal oscillations in food grain production often caused due to extreme weather conditions exacerbate the situation.

1.3
Climate Change Impact and Vulnerability

Climate change, especially aberrations in rainfall, temperature, soil, and water availability and quality, is emerging as a major threat to the food security and agricultural sustainability.

India with its huge population being dependent on agriculture and experiencing excessive pressure on its natural resources, coupled with its poor coping mechanisms, is highly vulnerable to the climate change, especially the poor and resource-poor farmers. The warming trend in India over the past 100 years has indicated an increase of 0.60 °C. Negative impacts of these changes on yield of wheat and paddy in parts of India due to increased temperature, increased water stress, and reduction in number of rainy days are already felt. Significant negative impacts have been projected with medium-term climate change, for example, yield reduction by 11–18%, depending on the magnitude and distribution of warming, eroding roughly 1.5% of the GDP per year.

The ICAR's National Network Project on "Impact, Adaptation, and Vulnerability of Indian Agriculture to Climate Change," started in 2004 involving 23 institutes/universities covering all major sectors of agriculture, namely, crops, horticulture, plantations, livestock, inland and marine fisheries, poultry, and natural resources such as water and soil, has the following objectives [8]:

- Quantify the sensitivities of current food production systems to different scenarios of climate change by integrating the response of different sectors.

- Quantify the least risk or "no regrets" options in view of uncertainty of global environmental change that would also be useful in sustainable agricultural development.
- Determine the available management and genetic adaptation strategies for climatic change and climatic variability.
- Determine the mitigation options for reducing global climatic changes in agroecosystems.
- Provide policy support for the international negotiations on global climatic changes.

The project has revealed both negative and positive trends in annual rainfall and minimum and maximum temperature. For instance, the project report, based on the past six decades' data, revealed an increasing trend in maximum 1-day precipitation in the west coast of Maharashtra, south Madhya Pradesh, east Bihar, Assam, north and west Karnataka, eastern Uttar Pradesh, western Jharkhand, and Ganga Nagar area of Rajasthan. A declining trend was observed in parts of southern Karnataka, western Maharashtra, northern Chhattisgarh, northern Madhya Pradesh, and western Uttar Pradesh.

As regards temperature, the number of cold days significantly declined in northwestern Madhya Pradesh, southern Chhattisgarh, and western Gujarat, and in parts of peninsular India. Number of cold nights declined in major parts of north India, south and west Gujarat, west Maharashtra, coastal Andhra Pradesh, southern Karnataka, northwestern Tamil Nadu, and northern Kerala, whereas it increased in north Chhattisgarh and northern Jammu and Kashmir states.

The occurrence of warm days significantly increased in parts of southern Rajasthan, western Madhya Pradesh, western Gujarat, northern Jammu and Kashmir, and Manipur, while it declined in parts of West Bengal, Jharkhand, southern Bihar, eastern Himachal Pradesh, Uttarakhand, northwestern Uttar Pradesh, and northern Haryana. In peninsular India, the number increased except in north and eastern Andhra Pradesh, southern Tamil Nadu, northern Karnataka, and in south and north of Maharashtra.

The report further showed that the emission of greenhouse gases has been increasing from agricultural soils. Emission of methane from Indian rice fields has remained almost constant, but emission of nitrous oxide is increasing. The CO_2 emission of marine fishing boats has increased.

The impact of climate change on wheat, rice, and maize yields will be significantly negative, varying from region to region. For instance, the climate change is projected to reduce the timely sown irrigated wheat production by about 6% in 2020 scenario. But, when late and very late sown wheat are also considered, the loss could be 18% in 2020, 23% in 2050, and 25% in 2080 scenarios, if no adaptation measures are followed (Figure 1.4). Likewise, in northwest India toward 2050 irrigated rice will have a yield loss of 15–17%. However, with adoption of suitable adaptation measures, the losses can be averted and even additional yields could be harvested. This underpins the importance of developing new techniques such as stress-tolerant

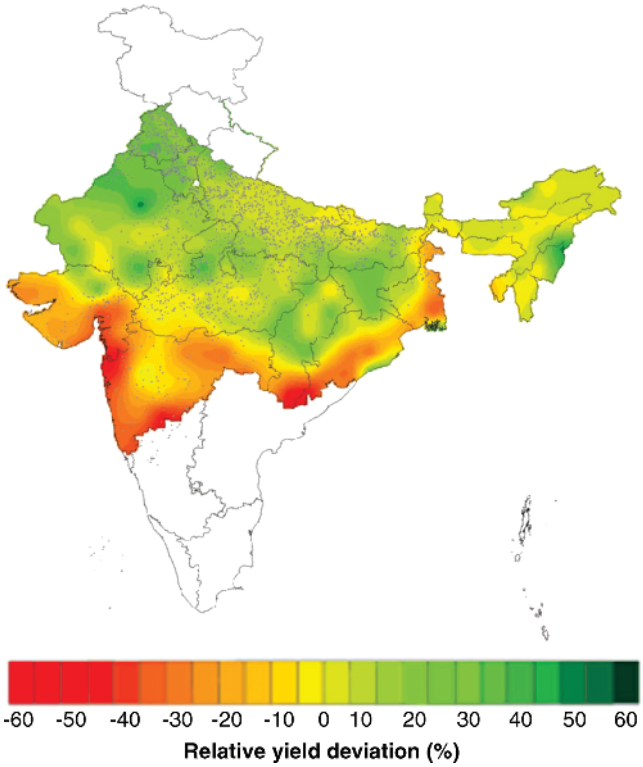

Figure 1.4 Net vulnerability of wheat in 2020 scenario. (*Source*: Ref. [8], with kind permission by Naresh Kumar, ICAR.)

varieties, efficient nutrient and water use technologies, and management practices suited to different agroecological regimes. Similar trends were projected for potato.

The simulation results had shown that the future climate change will have a positive impact on productivity of rainfed soybean and to a lesser extent on groundnut. The maximum positive impact was on chickpea productivity, ranging from 23 to 57%. The differential behavior of soybean and groundnut was due to increased rainfall and that of chickpea due to increased crop season temperature.

Regarding horticultural crops, the coconut model indicated positive impact on coconut yield in west coast and parts of Tamil Nadu and Karnataka and negative effects in east coast. The overall national level impact is simulated to be positive. The climate change is projected to shift the apple belt upward and cause shifts in cropping patterns.

As regards livestock, global warming is expected to lead to a loss of 1.6 million tons in milk production by 2020 and 15 million tons by 2050 under the usual scenario. Based on temperature–humidity index (THI, Figure 1.5), this loss in 2020 is valued at about Rs. 2661 crores at current prices. The loss will be highest in Uttar Pradesh. The crossbred cows are expected to suffer more from climate change.

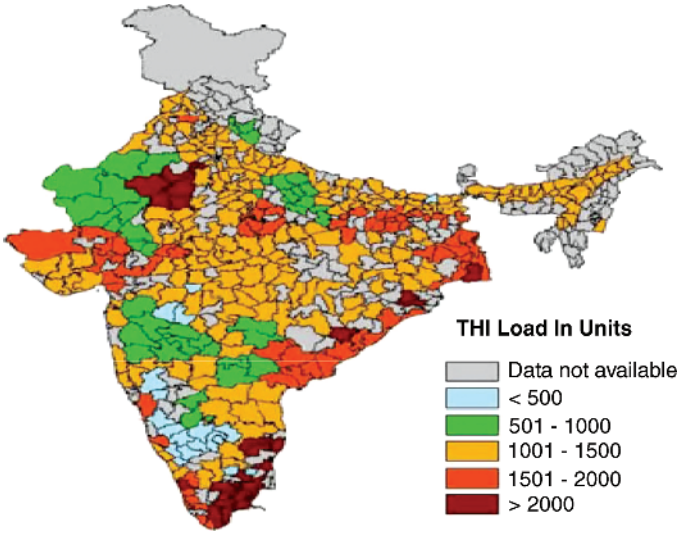

Figure 1.5 Annual THI load on livestock. (*Source*: Ref. [8], with kind permission by Naresh Kumar, ICAR.)

This underpins the need for conserving and improving local breeds that are tolerant to the climatic fluctuations and stresses.

As regards fisheries, even a 1 °C temperature increase would have profound impact. The marine and freshwater fishes will respond differently. Moreover, within each group, the interspecies differences in their responses to climate change will be profound. For instance with warming of sea surface, the oil sardine is able to find temperature to its preference in the northern latitudes and eastern longitudes, thus expanding its distributional boundaries. Likewise, the spawning season of several fishes will be changed. As regards inland fisheries, a major shift in spawning and breeding behavior of Indian carps has been seen. A number of fish species that were predominantly available in lower and middle Ganga about 50 years ago are now found in the upper cold water stretch up to Tehri.

As regards impact of climate change on natural resources, while in general there will be an increase in mean annual streamflow, it will decrease in summer months. With the increase in latitude, the annual runoff and soil loss will decrease. However, in most part of the country, mostly during monsoon season, the runoff and soil loss will increase considerably, being 6–12 times during 2071–2100 that of 1961–1990 in Coimbatore, Tamil Nadu. In other places, the increase will range from 56 to 309 % (Figure 1.6).

Water supplies will be impacted the most by the climate change. The flow of rivers originating in the Himalayas will be disrupted. For instance, Brahmaputra could lose 20% of its flow by 2050, adversely impacting the livelihoods of an estimated 28–41 million people. This underpins the need for sharp improvement in water use efficiency.

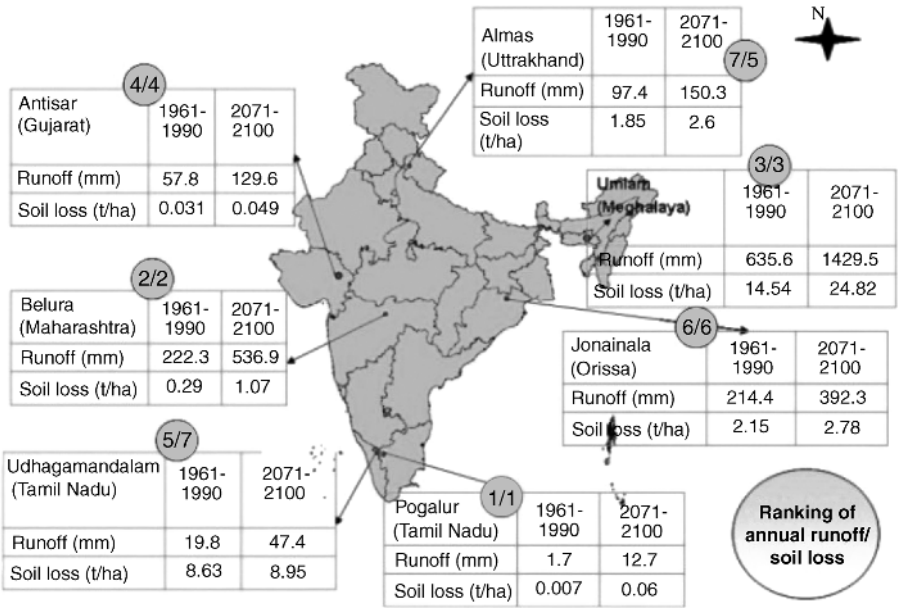

Figure 1.6 Annual runoff and soil loss during 1961–1990 and 2071–2100 from different agroecological regions of the country. (*Source*: Ref. [8], with kind permission by Naresh Kumar, ICAR.)

1.4
Natural Resources Management

Climate change impacts agriculture mostly through its impact on the natural resources, especially land, water, and biodiversity. In order to attain and maintain desired level of TFP growth, it is essential to launch an integrated management of these resources. As regards soil fertility management, thousands of well-equipped and well-functioning soil testing laboratories should be established and strategically located throughout the country (in which the private sector, agriclinics, and entrepreneurs can be effectively partnered) and each farmer should be issued a soil health card. Farmers should be oriented and convinced to get their soils tested on regular basis and manage their soil fertility through integrated nutrient application. Conservation agriculture involving technologies such as zero/reduced tillage is both time and cost saving in popular intensive cropping systems; for example, rice–wheat or maize–wheat rotation or potato plus maize (intercropped) and other diversified systems should be adopted extensively.

The sharp fall in water quantity and quality is the foremost threat to food security. Despite a viable national water policy being in place, water continues to be the most misused commodity. A countrywide campaign is required to conserve water and to

optimize its use as per resources. Other policy measures for water conservation and efficient use should include the following:

- Restoring water bodies around the country including village ponds, implementing the Million Well Recharge Program, promoting mandatory rainwater harvesting in rural as well as urban India, and managing water bodies and reservoirs by stakeholders and water users with the participation of Gram Panchayats and other local democratic bodies and self-help groups (SHGs) including women representatives.
- Withdrawing and not repeating all populist orders such as free electric supply to farmers by various State Governments that encourage excessive pumping of ground water and its wastage.
- Regulating and rationalizing the city water supply, and recycling the city wastewater to save the rivers from silting and pollution, thus increasing freshwater supply for domestic, agricultural, and industrial uses, and educating public at large continuously, making schools as base on importance of water and its rational use, and imposing penalty on the offenders. (Nearly Rs. 10 000 crores have gone down the drains under the Clean Ganges Campaign, but Ganga remains polluted as ever and is "dying" at places.)
- Extending the technologies for dryland farming to the small and marginal farmers and the National Rainfed Area Authority can have as its mandate the launching of second green revolution in dry farming areas beginning with pulses and oilseeds.
- On the basis of carbon credits, there can be water credits with each water user, be that a farmer, industrialist, or household, and he or she can earn credits or be punished accordingly.

The background paper for 12th Five-Year Plan has rightly identified the following NRM issues that require focused attention:

- Securing ecology of watershed and catchments.
- Cumulative environmental impact assessments (CEIAs) for vulnerable regions.
- Carrying capacity studies in selected river basins.
- Maintaining acceptable water quality and quantity through pollution control of water resources.
- Restoration of wetlands and lakes.
- Management of wastewater discharge from industrial and commercial establishments into major water bodies.

Several of the above issues were identified also in the past two Plans, but commensurate progress has not been made. Targeted activities should be defined under each district plan and judiciously implemented.

Bulk of the allocations to agriculture in the past Plans has gone to irrigation, which had significantly contributed to the Green Revolution process, but due to low water use efficiency at the farm level and losses in conveyance from source to the field, the overall payoff has been unsatisfactory. Misuse of water has resulted in widespread waterlogging and salinization. Several of the irrigation projects were delayed, but lately the accelerated completion of irrigation projects, micro-

irrigation, and participatory water management have been emphasized. India has been a leader in agroecological zoning and watershed-based integrated land and water use. Recent reviews of watershed programs have revealed that the programs had generally ignored the social, humanware, and equity concerns and had suggested to adopt watershed plus plus approach. A water productivity atlas should be prepared for the whole nation.

Rainfed regions, despite accounting for 40% of the population, 40% of food grain production, and 60% of the livestock population, are 13–15 times underinvested compared to irrigated command development. Effective rainwater harvesting and recycling and risk-proofing technologies and devices should encourage farmers to adopt improved farming practices and to bridge the huge yield gaps. Nearly 28 million ha of rainfed area has good potential for runoff harvesting. This harvested water can be used for at least one supplementary irrigation with high payoff yielding additional 9–10 million tons of food grains (Table 1.4).

Table 1.4 Additional production estimate of proper management of rains in India.

Crop group	Traditional production (million tons)	Additional production (million tons) with limited irrigation	
		Normal rains	Subnormal rains
Rice	7.612	3.549	3.776
Coarse cereals	8.300	4.410	3.415
Oilseeds	4.213	1.658	1.590
Pulses	3.717	1.152	1.078
Total	23.842	10.769	9.859

Source: Ref. [9].

Biodiversity, besides providing diversified food and nutrition resources, has direct implications on natural resources conservation, regional and global ecologies, and sustainability of agricultural production systems. Fortunately, India has been endowed with one of the richest biodiversity reserves in the Himalayas, river valley basins, costal areas, including offshore islands, and rain forests. But the pace and manner of development is presenting an imminent threat to the multiplicity of biodiversity. As a part of strategy to save and conserve, intertwining of biodiversity conservation should be an integral part of the large river valley projects, railroad construction, industrial and urban expansion, mining projects, and special economic zones (SEZs). Any further loss of biodiversity will have an adverse effect on the conservation and upkeep of land and water resources, which have a direct bearing on food and agriculture production, productivity, and food security. India having ratified the International Convention on Biodiversity (CBD) and being a party to the convention must be committed to conserve its biodiversity and also play a leading role globally. A national biosecurity umbrella encompassing food safety, environmental safety,

human and livestock health, and SPS and other risk management and regulatory provisions particularly under TRIPS should be created.

Forests and the benefits they provide in the form of food, income, and watershed protection have an important and often critical role in enabling people around the world to secure a stable and adequate food supply. Forest food resources are important to the most food insecure people because to them the forest food is most accessible and nutritious. Tropical forests present a range of uncultivated foods such as fruits, grains, seeds, leaves, roots, and tubers of food value, fish and a range of wild animals, as well as feed and fodder for animals. Need, however, is to check the deforestation and their degradation through increasing the awareness, educating the masses, and strict implementation of laws and policies. Rights of forest tribes, as detailed in the forest and tribal bill, should be protected.

Enhanced sustainability is a must for obviating instability in food availability and only a safe environment can sustain high productivity. Sustainable agriculture in safer environment is essential to save the environmental parameters in atmosphere, lithosphere, and hydrosphere while conducting agricultural operations. This is to be achieved through adoption of an ecotechnology approach encompassing integrated crop management (ICM) inclusive of integrated nutrient management (INM), integrated water management (IWM), and integrated pest management (IPM) – all grouped under "Green Agriculture." In addition to being eco-friendly, the technology should be cost effective and suited to the resource-poor farmers, encompassing the three E concerns for food security: economics, ecology, and equity. The paradigm shifts toward integrated farming system and ecotechnologies should be widely operationalized.

State and Central Governments, SAUs, KVKs, ICAR institutes, ATMAs, NGOs, private sector, farmers, women groups, small farmers' estates, cooperatives, Panchayati Raj Institutions, and other grassroot rural and community-based institutions must work in a participatory and interactive mode through adopting watershed-based approach that provides multiple entry points and synergistically converges efforts of the various partners. Panchayati Raj Institutions should be suitably strengthened to bring the necessary convergence at grassroot level.

Regional diagnostic centers equipped with modern facilities should be established for seed testing, soil and plant analysis, and diagnosis of insect pests and diseases of crops, animals, and fishes. These centers should be capable of addressing the farmers' problems of the region in all agricultural, horticultural, animal husbandry, poultry, fishery, postharvest management, and marketing subsectors. Also, they should have the backward links with district development programs and forward links with SAUs and ICAR institutes in the region. There has to be a strong team of specialists including socioeconomists placed at the centers. Selected KVKs and ATMAs with due strengthening could perform this role. Some of the KVKs should strategically be earmarked primarily for catering to the needs of women farmers. It may be remembered that other things being similar, women suffer more than men when exposed to climate change stresses. Therefore, women-specific adaptation and mitigation programs and plans should be designed.

1.5
Adaptation and Mitigation

Agricultural diversity is a manifestation of climatic adaptation. Farmers and farming communities have shaped and channeled the adaptation depending on technology availability, economic viability, and their socioeconomic capacity. A two-dimensional approach is needed to increase adaptive capacity of agriculture to climate change. In the longer term, adaptation to increased mean temperature and rainfall intensity will be important. In the short term, adaptation to unpredictable weather extremes such as drought, flood, heat, and cold will assume priority. Short-term land and water use plans must therefore be developed for ensuring climate resilience.

Adaptation should include autonomous as well as planned measures. Autonomous adaptation – the ongoing implementations of existing knowledge and technology in response to changes in climate – would include variety and crop substitution, altering irrigation, water management practices, fertilizer and other inputs timing, quantity and mix to cut cost without compromising yield, water harvesting, watershed management and increased water use efficiency, community-based management of water, adjusting overall farming system, and making intelligent use of weather forecasting.

The long-term adaptation is a must now. It will need additional knowledge, information, technologies, investments, infrastructures, and institutions integrated with the decision support system. Insurances, safety nets, cash transfers, and other risk management options to reduce vulnerability to shocks are also important parts of the solution. Greater emphasis must be placed on land and water use planning, monitoring, and community action. The Government must have a dynamic policy, plan, and strategy on climate change management to address the various issues.

As regards mitigation, agriculture being both a victim of and a contributor to GHGs and other environmental pollutions, an integrated resource and pollutant management strategy should be adopted. As regards GHGs, a three-pronged approach based on reducing emissions, enhancing removals, and avoiding (or displacing) emissions should prove effective. Grassroot organizations, primary agricultural cooperatives, and other cooperative systems should be empowered to increase carbon sequestration and their participation in the carbon market and income generation from environmental services without jeopardizing short-term production at smallholder farms. Governments, international agencies, private sector, farmers' organizations, CSOs, investors, and donors should collaborate in developing a win–win situation.

Research on genetic improvement, promotion of resource conservation technologies, and diversification would help the smallholder farmers in empowering them to adapt to and cope up with the situations. Research on organic recycling, alternative sources of energy, and enhanced and efficient biomass production and utilization will have high payoff. Successful models of identifying and applying appropriate technologies and supporting collective action of farmers with natural

resource management in the most fragile environment and in tribal areas should be up- and outscaled. Systems such as mobile telephony for carrying the viable technologies, weather forecasts and weather-related information, and information on markets, prices, and pest and disease management should be promoted.

As the smallholder farmers are most vulnerable, an affordable and effective insurance system has to be introduced and implemented. The main risks of such farmers are related to (i) crop, (ii) weather, (iii) life, (iv) health, and (v) price. Whereas an effective price support system and marketing infrastructure may cover price-related risks and National Agriculture Insurance Schemes may cover the crop-related risks, the ITGI's products relating to weather insurance, general insurance, health insurance, and accidental death and injury insurance are particularly useful for climate change management. Rural cooperatives and other private organizations could become nodal points and agents for these insurance products and cover their members. A transparently and professionally managed Agriculture Risk Fund, as recommended by the National Commission on Farmers, should be established to insulate extremely poor and distressed farmers in the event of extreme weather and natural disaster conditions [10].

Since climate change poses complex challenges such as multiple abiotic stresses on crops and livestock, shortage of water, land degradation, and loss of biodiversity, a focused and long-term research is required to find solutions to the problems specific to our country. In this context, it is gratifying to note that a National Initiative on Climate Resilient Agriculture (NICRA) with a substantive budgetary outlay has been launched by the ICAR under the supervision of NRM Division with implementation by CRIDA. The scheme attempts to develop and promote climate resilient technologies in agriculture that will address vulnerable areas of the country. The outputs of the scheme will help the districts and regions prone to extreme weather conditions such as drought, floods, frost, heat waves, and so on to cope with such extremes, with special consideration to small and marginal farmers in rainfed, coastal, and hill areas.

The Initiative, however, should develop common metrics and tools for demonstrating the impacts on a wider scale, and also for benefiting from external financing (e.g., Clean Development Mechanism, Adaptation Fund of the Kyoto Protocol, Green Climate Fund, and private sector sources) to support community-based efforts to implement CSA practices and projects. In this context, effective GHG accounting methods should prove helpful.

1.6
Climate Resilient Agriculture – The Way Forward

The developing countries bear 75–80% of the costs of damages caused by the changing climate and the disturbed ecological, environmental, economic, social, and biological settings. Recognizing that agriculture is both a victim of and a contributor to GHGs and other environmental pollutions, a two-pronged approach to reduce the emission on one hand and to develop adaptive measures to increase

agricultural resilience on the other hand will be needed. Fortunately, alternative agricultural practices designed for specific agroecologies are proving effective in reducing GHG emissions from agriculture and at the same time in improving yields under extreme weather.

The road ahead to agricultural adaptation to climate change should therefore integrate technology, policy, and finance options toward lowering emission and promoting inclusive growth. Agroclimatic zone-specific approaches for management of water and other natural resources through adaptation of appropriate agricultural practices such as integrated watershed management, designer crops that may tolerate extreme biotic and abiotic stresses, conservation agriculture, system of rice intensification (SRI), development and use of climate analogues, and carbon finance for adaptation should be actively promoted.

It is well recognized that growth in agricultural sector of developing countries reduces hunger and poverty more effectively than do urban and industrial growth. This is particularly true under the fast changing climate. Bridging the yield gaps and enhancing sustainability of production systems should be the main pillars of achieving the desired accelerated and inclusive agricultural growth. The following actions are called for:

- Getting technology moving and ensuring access of farmers to the technology by re-establishing a trained, retooled, and dedicated cadre of extension workers, and strengthening of agricultural research and technology development.
- Increasing investment, efficiency, and systems support, rationalizing subsidy, and ensuring timely flow of cost-effective quality inputs and credit, insurance, and other institutional support systems.
- Augmenting the physical and economic connectivity of farm to market, postharvest operations including the role of food processing industries, cautious diversification without jeopardizing food security, and ultimately enhancing farmers' income and rural employment security.
- Promoting inclusiveness by enhancing access to land, water, credit, market, skills, and technology on the part of the poor and women, especially in the hot spots.

Food grain production and productivity, particularly of small and marginal farmers, should be accelerated to achieve the desired growth rate and equity. While the ongoing miniaturization of farm sizes should be halted and reversed through promoting off- and nonfarm rural employment, land reforms and land leasing, and other measures, improving small farm productivity must be the most important single development strategy to empower the resource-poor farmers to manage the stresses caused due to climate change. Village seed and food banks, preferably managed by women, should be established in each Panchayat.

Low-yield areas should be mapped and location-specific causes of the productivity gaps and land factor productivity should be identified and specific land and water use decisions should be promoted by restructured and retooled State Land Use Boards to realize the yield and income potential. Agricultural diversification should be promoted in consonance with market opportunities, farmers' income, and ecological sustainability.

The slowdown in livestock and horticulture subsectors where huge yield gaps and unexploited potential exist should be arrested and small farm estates for horticulture, cotton, poultry, and aquaculture should be created to promote group farming and postharvest management. Knowledge-based and market-led diversification and extension should be promoted by institutionalizing the Every Village a Knowledge Center or Gyan Choupal movement. Climate change extension agents should be deployed in village clusters and should be equipped with relevant information and communication tools and devices.

In the livestock subsector, productivity of livestock in India is low due to fodder, feed, healthcare, market, and price constraints. Integrated crop–livestock–fish farming systems, cooperatives (Amul being world famous experience), and SHGs, especially women SHGs for livestock and agriclinics operated by veterinary and farm science graduates and paravets, coupled with fodder and feed banks, will immensely increase the productivity and income of livestock owners. Livestock insurance should particularly be accessible to smallholders. In view of the setback to poultry industry due to bird flu outbreaks, quarantine and testing facilities at all ports of entry should be established. Poultry rearing should be recognized as an agricultural activity and appropriate support should be extended to backyard poultry farmers to establish smallholders' poultry estates.

As regards the fisheries subsector, the following steps are suggested for accelerating production:

- Introduce integrated coastal zone management and scientific fish rearing, harvesting, and processing, including introducing mother ships, and develop suitable dynamic policies and governance, particularly for the management of exclusive economic zone (EEZ) extending to nearly 2 million km^2 of sea surface, which amounts to two-thirds of the land surface available to India. Strengthen early warning systems and instant communications to escape damages from typhoons, cyclones, and other weather aberrations.
- Undertake and institutionalize well-planned Aquarian Reforms to provide landless labor families access to village ponds and other water bodies in the public domain for aquaculture, and clarify property and use rights.
- The National Fisheries Development Board (NFDB) should promote the Aquarian Reforms and ensure congruence of ecology, economics, gender equity, and employment generation and should help resolve the conflicts between aquaculturists and agriculturists as well as resolve problems of local population due to salt water entering into the aquifer and pollution caused by intensive systems of aquaculture, and settle conflicts related to seaweed farming and introduction of exotic carps and other alien invasive species.
- Establish Fish for All Training and Capacity Building Centers (decentralized) for comprehensive training of the capture/culture–consumption chain, quality, hygienic handling, and biosecurity (with due attention to needs of fisherwomen) to enable fisher families to take up additional income earning activities.
- Institutionalize Responsible Fisheries (ecosystem approaches), promote wider application of semi-intensive production systems, and strengthen research and

extension for integration of aquaculture and other subsectors of agriculture and public–private partnership particularly in hatcheries and stocking programs.

Under the United Nations Framework Convention on Climate Change (UNFCCC) in 2011, the Commission on Sustainable Agriculture and Climate Change encouraged policy action to help achieve food security while addressing climate change. It recommended seven priority actions [11]. Two of the most important priority actions in the context of climate smart agriculture (CSA) are (1) sustainably intensify agricultural production while reducing emissions and other environmental impacts and (2) create comprehensive information systems on human and ecological dimensions. Expanding CSA that results in increased food production, limits greenhouse gas emissions, and prepares for future climate change is a major goal and challenge especially in agriculture-based countries such as India where rural livelihoods depend primarily on shrinking and degrading ecosystems.

Research and technology development (supported by policy and institutions) will need to be geared to meet the veritable challenges. The much needed congruence of high productivity and sustainability in face of the intensifying volatilities due to climate change, biotic and abiotic stresses, and market instabilities, let alone the challenges of adequately feeding the swelling population from shrinking and degrading natural resources, can be underpinned only by developing smart technological solutions and innovations. New and modern sciences and cutting-edge technologies, especially intensive characterization of germplasm, molecular breeding, and genetic engineering for crop improvement and development of designer crops, coupled with associated resource management practices, including indigenous knowledge, practices, and technologies, will increasingly be called upon to provide the desired solutions.

There is a need for more integrated research and improved knowledge systems on the specific agricultural production methods that would work best for individual regions, farming systems, and landscapes. In addition, for agricultural practitioners in general, there is a need for public domain systems that provide information on "repeated observations" of successful CSA practices that are suitable for both large- and smallholder agriculture. Impacts of such practices should be tracked and reported through (1) design of standardized tracking metrics for measuring the impacts of CSA practices/strategies in terms of food production, GHG emissions, and climate resilience, (2) development or adoption of a public domain system for reporting and illustrating the results of these efforts, and (3) the potential establishment of a private sector-supported Climate Fund providing a mechanism for corporate to participate in the promotion and sustainability of climate smart agricultural practices.

The system may customize data collection and communication of successful project activities and adapt the Web-based software tool, such as CarbonCounts™ being used for monitoring, reporting, and verification (MRV) in Mexico for tracking of GHG mitigation and adaptation activities. Some modifications to this tool would likely be necessary; otherwise, a reporting tool specifically for Indian activities should be designed. Further, national investments in climate financing should

be streamlined to attract sustained national and international funds. With the increasing emphasis on corporate social responsibility (CSR) initiatives, a "Climate Fund" should be established to leverage the financial capacity of the private sector to direct additional philanthropic resources toward climate-friendly adaptation interventions that will target and support the advancement of India's poorest farmers and help uptake of CSA practices.

Finally, commensurate with priority policy actions, as also suggested by UNFCC/CSACC, the following policy options are needed: (1) integrate food security and sustainable/resilient agriculture into global and national policies, (2) increase global and national investments in resilient/sustainable agriculture and food systems, and (3) target programs and policies to assist vulnerable populations. Scientists should inform policies regarding the relative importance of adaptation and mitigation across various subsectors of agriculture (crop, livestock, fishery, and forestry) and provide guidelines to ensure synergies for improving food security and livelihoods. Effective methodologies should be developed for assessing risks and benefits and for evidence-based evaluations to enable scaling up to "safe operating space."

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