Observed vis-à-vis projected crops yield in India in the context of climate change

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Agriculture is the most weather-dependent human activity and hence climate change significantly impacts agricultural productivity. In the present study, an attempt has been made to review the existing literature to document and assess the projected crops yield vis-à-vis actual yield of various crops in India. It has been found that most of the studies have projected decline in yield of crops due to climate change up to 2020 and in future. However, actual yield of various crops in India has shown increasing trend till date. Adaptation measures like the release and adoption of new varieties of crops and increase in area under irrigation, use of more chemicals and fertilizers, improved mechanization of agricultural operations, etc. have contributed in enhancing the crop yield. Thus, such measures should be strengthened by the Government for sustainable agriculture.

Keywords: Agriculture, climate change, crop yield, projections.

IN India, the agriculture sector employs about 45% of the workforce. It has strategic importance for ensuring food security of the large human population, although its share in the national income has been declining with the development of Indian economy[1]. Therefore, the steady growth of agriculture is a must for the progress of our country. Agriculture is a weather-dependent activity in India and nearly 48% of the total cropped area is still dependent on the uncertainties of monsoon rainfall[2,3]. Weather plays an important role in determining the growth of crops and their yield. Even minor changes in the normal weather hinder the efficiency of crop production. Climate change through changes in temperature and precipitation affects the soil conditions, salinization and soil water content. Therefore, it may negatively impact agricultural production, which will have grave consequences for human society[4].

Changes in agricultural policies, uncertainties in the market, terms of trade, availability of water resources and the uncertainties driven by climate change, including droughts and floods, influence the performance of the agriculture sector and its production[5]. Climate changes occur due to an increase in temperature on account of rising levels of greenhouse gases (GHGs) in the environment, such as carbon dioxide, ozone, methane, nitrous oxide and chlorofluorocarbons. Since the agricultural sector is also one of the contributors of GHGs and is affected significantly by a change in temperature, the concentration of carbon dioxide and rainfall pattern, more emphasis must be given to climate change and its effect on agriculture in the future[6–12].

Many of studies have been conducted to analyse the impact of climate change on agriculture in India and across the world. Many have projected changes in crop yield due to climate change in the short and long run. In order to determine whether the projections made by researchers on the impact of climate change on crop yield are close to the actual yield or at variance, in the present study, we examined the projections on changes in crop yield in India up to the year 2020 and compared them with the actual data. It is also essential to understand the underlying reasons for the deviation in actual yields from the projected yields. This study further explores the efforts of the Government and other stakeholders, including researchers, farmers and development agencies working to minimize the negative impact of climate change. A discussion on the above issues will improve our understanding of the impact of climate change on agriculture and help design appropriate adaptation strategies to deal with future impacts of climate change on Indian agriculture.

Methodology

We reviewed the available literature on the projections of crop yield due to the impact of climate change across different regions in India. Only seven studies projected crop yield due to climate change up to 2020 and hence were selected for further analysis. The projected yield of various crops across the country was taken from the above studies. Most of them have projected changes in yield in percentage from the baseline, while some have provided both baseline yield and projected yield. The actual estimate of crop yield

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for the period starting from 1966 till 2020 was taken from the Directorate of Economics and Statistics (DES), Ministry of Agriculture and Farmers Welfare, Government of India. The trend line of actual crop yield was fitted to determine whether actual data show a declining or increasing trend over the period compared with the projected decline or increase in crop yield due to climate change.

Climate change and crop production

Climate change and its impacts have been widely recognized as the forefront of policy discourse in India. The effect of climate change on crop yield could be negative or positive depending on the type of crop and environmental conditions[13]. The general consensus is that there will be an adverse as well as favourable effect of climate variability on region-specific agriculture in the absence of suitable strategies to deal with climate change. Some of the impacts will be slow, enabling the farmers and the Government to respond with appropriate strategies. However, some of the climate change variables may have unexpected outcomes on agricultural productivity, which may not be known easily, or proper strategies and resources may not have been put forward. Droughts' damage due to storms and flooding are expected and thus the impacts of climate change on agricultural productivity are projected. Extreme weather conditions such as droughts, floods, hailstorms and cyclones are direct threats to crop cultivation. Moreover, minute changes in weather during the vital phases of crop development can considerably impact the crop yield. Climate change may also have some indirect impact on the harvested areas. For example, a 19% decline in monsoon rainfall in 2002 resulted in an 18% decline in foodgrains production in India during 2002–03 (ref. 14).

Extensive literature has addressed the impact of climate change on agriculture which identified a wide range of factors influencing its vulnerability such as the type of crops grown, awareness of climate variations, soil content, financial constraints and the ability to adopt remedial measures related to climate change. It has been estimated that the decline in rice yield was lower in eastern India compared to all the other regions[15]. Mean grain yield of control crops was 7.9 t ha^{-1} in the eastern region compared to 8.7–9.9 t ha^{-1} in other regions of India. The southern and western parts of the country, having relatively low temperatures are likely to show less increase in the yield of rice in improved management conditions under climate change compared to the northern and eastern regions of India. The effect of rainfall on the yield of irrigated crops varies with location[16]. An increase in temperature with elevated CO_2 led to an increase in the yield of soybean in Himachal Pradesh[17]. A study conducted using the crop simulation modelling approach reported an increase in minimum temperature and negative trends in solar radiation, which resulted in a decline in the potential yields of wheat and rice in the Indo-Gangetic Plains[18]. The decline was 356 kg ha^{-1} $decade^{-1}$ in rice yield for PRECIS output and 217 kg ha^{-1} $decade^{-1}$ for RegCM3 output without considering CO_2 fertilization effect[6]. However, considering the CO_2 fertilization effect, the decline was 135 kg ha^{-1} $decade^{-1}$ for PRECIS output and an increased yield of 24 kg $ha^{-1}decade^{-1}$ for RegCM3 output.

It has been estimated that the rice yield will increase in southern and central India by the middle of the next century[19]. Moreover, the yield would decline in the northwest region under irrigated conditions as due to decline in rainfall during the monsoon season. However, the increase in rainfall in Kerala makes up for the negative impact on yield of rice due to the rise in temperature[20]. However, the increased CO_2 concentration causing any possible gain would be offset by the decline in yield generated by shorter growing periods and higher temperatures[21]. While rice yield is at risk of the increase in minimum temperature, wheat yield is sensitive to the increase in maximum temperature[22]. Moreover, there is variation in the impact of climate change on yield of sugarcane across states in India due to geographical location, diversity in climatic factors, natural resources, irrigation facilities, use of advanced technologies and fertilizers, farm management practices, agricultural research and development, and agricultural development policies[12].

Projected vis-à-vis actual yield of crops

As climate change will result in a rise in temperature, changes in rainfall and other climatic variables, researchers have projected its impact on various crops for the future. Table 1 presents the projected yield of various crops in different regions of India. Figures 1–3 present the trends in the actual yield of crops over time. The studies conducted in Tamil Nadu using the panel data approach and the Ricardian approach have projected a decline in the yield for 2020 over the base year except for maize[23,24]. However, the actual yield of rice, sugarcane, paddy, groundnut and sorghum has increased over the period, as depicted by the trend line (Figures 1 and 2). In the case of maize, the yield was projected to increase due to climate change and the actual yield also increased over time (Figure 3). Studies in the Gomti river basin[25] and Bhavani basin[26] using Soil and Water Assessment Tool (SWAT) projected yields of rice and wheat for 2020. Comparison with actual data revealed that rice and wheat yield increased significantly compared to the projected yield. The yield of wheat has been increasing because it has been irrigated using shallow aquifer water which has hindered the adverse effect of a decrease in rainfall[25]. A study in Punjab also revealed that the actual yields of rice and wheat had increased compared to projections of a decline due to climate change[27] (Figure 1). Using the InfoCrop model, a study projected a decline in rice yield during 2020 in India, whereas the actual yield showed an increasing trend over time in various regions as well as for the entire

Table 1. Projected changes in crop yield due to climate change in India

Reference	Methodology used for the projection	Base year	Year of the projection	Region/ State	Projected yield (q/ha) during 2020			
					Crop	Base period yield	Change in yield projected (% q/ha)	Projected yield
23	Panel data	1971–2009	2011–2020	Districts of Tamil Nadu	Rice	27.72	0.55 q/ha ↓	
					Sorghum	10.28	0.75 q/ha ↓	
					Maize	17.46	0.29 q/ha ↑	
24	Ricardian model	1990–2001	2020	Districts of Tamil Nadu	Paddy	33.97	3.52 ↓	32.78
					Sugarcane	839.3	13.40 ↓	726.80
					Groundnut	17.45	7.04 ↓	16.22
25	Soil and Water Assessment Tool (SWAT)	1995–2002 (rice) 1996, 1998–2003 (wheat)	2020	Gomti river basin	Rice		5.5–6.7 ↑	
					Wheat		13.9–15.4 ↑	
27	Panel data 2020	1986–2015	2020	Districts of Punjab	Rice		2.56 ↓	
					Wheat		1.93 ↓	
28	InfoCrop model	2000–2007	2020 (2010–2039)	All-India	Rice		~4 (irrigated) ↓	
							~6 (rainfed) ↓	
				Punjab			6–8 (irrigated) ↓	
				Andhra Pradesh			3–22 (rainfed) ↑	
				Chhattisgarh			8–10 (rainfed) ↓	
26	SWAT model	1971–2010	2011–2040	Bhavani Basin	Rice	47.62	*Kharif* 3.15 ↓	46.12
						42.16	*Rabi* 16.63 ↑	49.17
29	InfoCrop model	2006–2008	2020	Patna, Bihar	Rice	44.11	2.7 ↑	45.32

Source: Authors' compilation based on the studies reviewed.

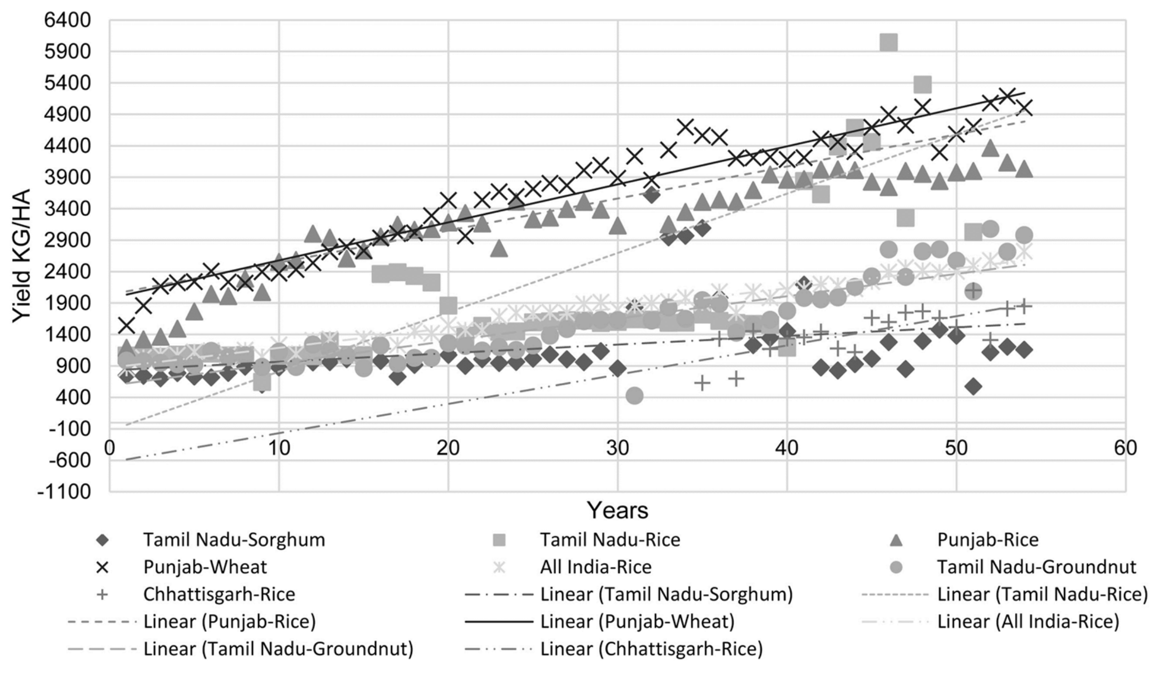

Figure 1. Trends in actual yield of crops in various states showing increase in projected yield due to climate change.

India[28]. A study conducted using the InfoCrop model has shown an increase in projected yield in 2020 over the base period[29]. Moreover, the trend in actual yield showed a more significant increase than the projected yield. Therefore, it can be clearly seen that the actual yield has increased significantly compared to the projected decline or rise in yield as depicted by the linear trend. This is due to increased rainfall in the regions, which has positively affected crop yield. The above studies have highlighted the impact of climate change on different crops in India. Moreover, there is variation in the methodology used in different studies.

From the above discussion, it is clear that projections on crops yield due to climate change in all the studies for 2020 have deviated from the actual yields and in most

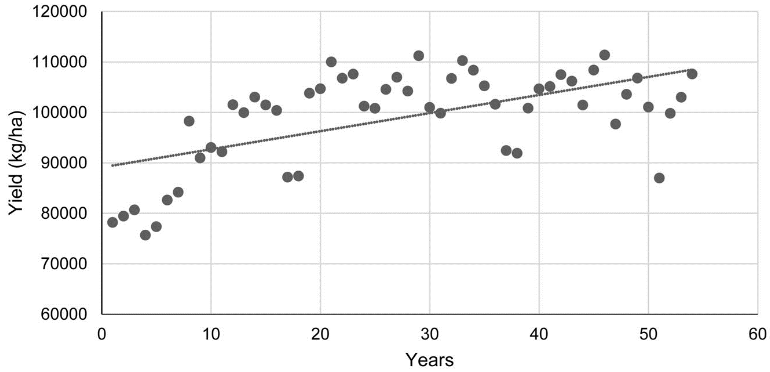

Figure 2. Trend in yield of sugarcane in Tamil Nadu over the period.

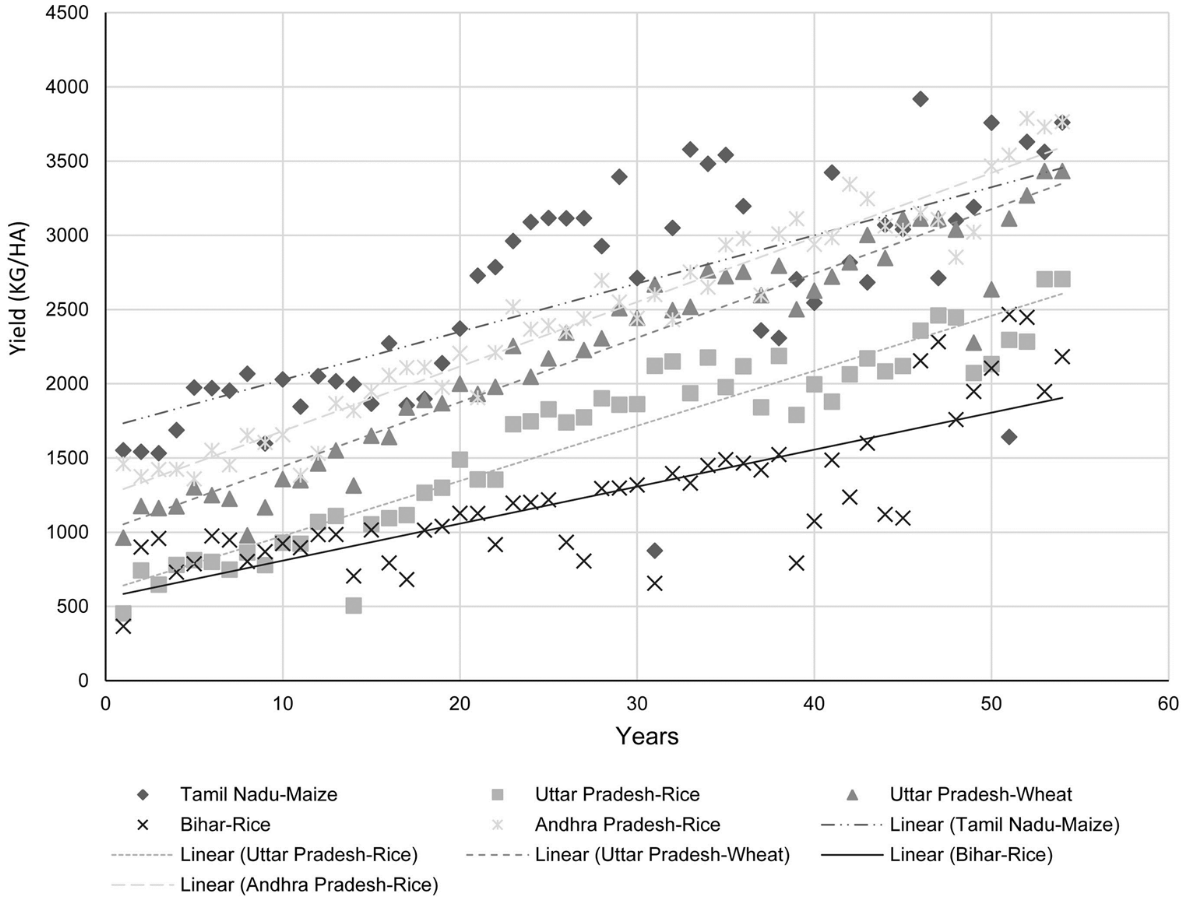

Figure 3. Trends in actual yield of crops in various states showing decline in projected yield due to climate change.

cases, the actual yield remains higher than the projected yield. Thus it is important to find the reasons behind such differences in actual and projected crop yields. The probable reasons could be issues in the methodology used in these studies, the selection of variables for the estimations in the models or various adaptation measures taken by farmers and policy-makers in the country. The adaptation measures include the introduction of improved varieties of crops for higher yield and abiotic stress tolerance, an increase in area under irrigation, micro-irrigation techniques, more farm power availability, an increase in credit availability and enhanced use of inputs.

One of the important methodologies used in the studies was the crop simulation method, which did not include adaptation to climate change conditions by the farmers[28,29]. Moreover, it could overstate the damage caused by changing climate[30]. The Ricardian approach used cross-sectional data[24], but failed to consider the time-independent, location-specific factors such as soil quality[23] which could result in deviations in actual and projected figures. The estimates are hindered by the unavailability of land prices. Researchers have also used the panel data approach in their studies[23,27], which has a large number of unknown parameters in the error process resulting in unreliable assessments of the standard errors of the estimated coefficients[23]. The SWAT model has been applied in a few studies[25,26], which has helped in developing adaptation strategies to sustain the productivity of crops. Therefore, the methodological limitations could be one of the factors for the projection of yields which did not match the actual yield data across different regions of India.

Further exploration of the above studies provided insights into the variables used in the model analysis. A study has demonstrated an increase in rice yield due to increased rainfall during the end of the century, which indicates rainfall is an important factor impacting agricultural production. The model uses maximum and minimum temperature, daily precipitation, solar radiation, relative humidity and wind speed in the study conducted in the Gomti river basin[25]. However, a study in other states and at the all-India level considers the location-wise daily data on solar radiation, rainfall, maximum and minimum temperature, vapour pressure and wind speed[28]. A study using the Ricardian approach in Tamil Nadu considered annual rainfall, maximum and minimum temperature and diurnal temperature variation[24], whereas another study in the same state used normal rainfall, which is the moving average of five years (because farmers adapt to the climate change in agriculture over the time) and mean temperature to examine the impact[23]. Such studies can be improved by including additional factors such as the amount of reservoir water for irrigation. Researchers using panel data in their analysis in Punjab had considered monthly minimum and maximum temperature and rainfall data to assess the impact of climate change[27]. The SWAT model considered solar radiation, maximum and minimum temperature, and rainfall[26], while maximum and minimum temperature, rainfall, soil information and varietal parameters were used in a study in Bihar[29]. Therefore, various studies have considered different factors to assess and make projections of impact of climate change on the agricultural sector, which might have resulted in the difference in projected and actual yields during 2020.

However, strengthening the process of adaptation is the logical option to deal with the extremes of climate change. Different adaptation measures have been suggested in various studies to reduce the impact of climate change on agriculture in India. Stress-tolerant, high-yielding crop varieties[28,31,32], crop insurance, easy availability of credit, irrigation facilities[23,25], agronomical management[28] such as intercropping, crop diversification and mixed cropping techniques and modern inputs should be used by the farmers to deal with a yield loss of different crops due to climate change[10]. Irrigation can negate the harmful effects of climate change on rice, groundnut, wheat and rapeseed-mustard crops[32–34]. Moreover, change in planting dates[35] and varieties, adopting crop management strategies[28], high-input delivery[32,36], development of adverse, climate-tolerant genotypes and land-use systems, risk management through weather-based crop insurance, improved land-use policies[37], location-specific needs[38] and application of biofertilizers[33] increase the adaptive capacity of crops. Farmers in Tamil Nadu, Karnataka and Kerala should adopt soil moisture conservation, provision for nutrient supply and proper drainage to reduce the impact of climate change[36]. Use of improved crop varieties along with adequate irrigation and balanced doses of fertilizers are essential to sustain the crops yield in future[28,35,39].

Adaptation measures to reduce the impact of climate change

The stakeholders in crop production, such as farmers, researchers and development agencies, have contributed to developing adaptation strategies and policies to reduce the impact of climate change on agriculture. As a result of these measures, there has been an improvement in the yield of crops in India despite the projections of a decline due to climate change. Figures 1–3 show the increasing trend with fluctuations in crop yield in various states as well as the all-India level between 1966–2020. Farmers possess knowledge about climate and agriculture, which urges them to take adaptation decisions to reduce losses in crop yield due to change in climate. They have made changes in planting and harvesting dates and adopted high-yielding varieties that consume less water and are drought-heat tolerant. Farmers have also adopted improved farm machinery, which has enhanced input use efficiency.

The Government of India has taken a number of initiatives to improve the availability of quality inputs for use at the farmer's field, which would help improve the crop yield and reduce the adverse impacts of climate change on the yield. Due to efforts by the Government, the availability as well as the use of agricultural inputs like fertilizers, quality seeds, pesticides and agricultural credit have improved over time. Table 2 provides details of the same during recent years. It is clear from the table that the use of chemical fertilizers and pesticides has increased between the triennium ending 2009–10 and 2019–20 on an all-India basis as well as in the states of Punjab, Bihar and Uttar Pradesh, except Tamil Nadu. Bihar has registered a significant increase in the consumption of fertilizers (59.51 kg/ha) during the above periods. Moreover, the distribution of quality seeds and agricultural credit disbursed by the banks have shown rapid improvement, which might have helped enhanced crop yield despite climate change in the country.

It is important to note that there has been an increase in the area irrigated under crops in different regions (Table 3). The area irrigated has increased by 8.09% under rice crops in India. The percentage area irrigated has shown a quantum increase from 70.11 to 86.26 for rice crops in Uttar Pradesh.

Table 2. Status of climate adaptation measures in agriculture

Particulars	TE 2009–10	TE 2019–20	Change (%)
Distribution of certified/quality seeds (lakh quintals)	217.3	352.05	134.72
Use of pesticides (1000 tonnes)	42.44	61.59	19.15
Fertilizers consumption (kg/ha)			
Tamil Nadu	200.56	167.90	–32.67
Punjab	222.82	227.11	4.29
Bihar	169.13	228.64	59.51
Uttar Pradesh	158.96	172.89	13.93
All-India (average)	126.97	131.19	4.21
Agricultural credit distributed by scheduled commercial banks (billion Rs)			
Bihar	84.67	395.53	310.86
Uttar Pradesh	347.00	1,365.84	1,018.84
Tamil Nadu	348.33	1,637.10	1,288.77
Punjab	175.00	692.89	517.89
All-India	3,246.33	13,056.99	9,810.65

Source: Agricultural Statistics at Glance data 2007–08 to 2019–20.

Table 3. Crop-wise area irrigated and growth rate

State	Crop	Percentage area irrigated		Percentage change over time
		TE 2002–03	TE 2018–19	
India	Rice	53.42	61.51	8.09
Punjab	Rice	99.29	99.62	0.33
	Wheat	97.95	99.16	1.21
Uttar Pradesh	Rice	70.11	86.26	16.15
	Wheat	96.45	98.97	2.52
Tamil Nadu	Rice	92.34	92.97	0.63
	Sorghum	10.21	9.93	–0.27
	Groundnut	32.88	39.12	6.25
	Maize	31.47*	33.68	2.21
	Sugarcane	100.00	100.00	0.00
Bihar	Rice	54.36	67.74	13.37

Source: Land Use Statistics at a glance data 2000–01 to 2018–19 (ref. 45).
Note: Due to data inconsistency regarding the area irrigated under maize crop in Tamil Nadu, triennium ending 2004–05 was considered.

Bihar has also shown improvement in area irrigated with a 13.37% change, as the crop is grown under irrigated conditions without any water stress[26]. The micro-irrigation technique addresses the problems of emission of GHGs and water scarcity in agriculture. The sprinkler system is most suitable for field crops, which increases water use efficiency to the extent of 50–90%. Punjab has the highest groundwater development of 149%, followed by Rajasthan with 140% (ref. 40). Tamil Nadu, Gujarat, Maharashtra, Karnataka and Andhra Pradesh together dominate the total drip-irrigated area, while Karnataka and Rajasthan dominate in the case of the sprinkler system[3]. Apart from this, many improved cultivars of crops have been introduced by the states and Central government, which may have contributed to improving crop yield across various regions of India (Table 4).

Farm mechanization has played an important role in the climate-proofing of agriculture. In view of the present challenges in the production system, future growth has to come from improvements in farm mechanization[41,42]. In recent years, farm mechanization has improved tremendously and farm power availability has increased from a mere 1.87 kW/ha in 2011–12 to 2.76 kW in 2020–21 (ref. 43). This has led to improvement in crop yield.

Conclusion

There are evidences in the literature of an increasing trend in the climatic variables in India over the years. This has affected the performance of the agricultural sector. An extensive review of the literature has been made in the present study, which outlines the deviations in the projected and actual yield of crops in India. While two studies[28,29] used the InfoCrop model, Palanisami *et al.*[24] assessed the impact using the Ricardian approach and used the panel data approach[23,28]. However, Abeysingha *et al.*[25] and Kumar and Sidana[27] considered the SWAT model all of which have different assumptions. Abeysingha *et al.*[25] have projected

Table 4. Improved crop varieties released across regions in India

Crop	Region/State	Varieties
Rice	Uttar Pradesh	CR Dhan 501, Chinsurah Rice, US 312, NDR 2065, CSR43, TPS 5, Shiats Dhan-1, Shiats Dhan-2, Shiats Dhan-3, Shiats Dhan-4, Shiats Dhan-5, Narendra Lahar and Narendra Parag, Pant Basmati 1, Pant Basmati 2, Pusa Basmati 1609, Sukhadhan 5 and Sukhadhan 6, 28P09, 28S41, CO 51, DRR Dhan 50, 28P67, BIO 799, CR Dhan 909, CR Sugandh Dhan 908, DRR Dhan 51, HRI 183, NPH 8899, VNR 2228, CSR 56 and CSR 60, CSR 46 and ADT 51
	Tamil Nadu	CR Dhan 501, Chinsurah Rice, US 312, CO (R) H-4, CR 1009 Sub 1, TKM 13, MDU 6, Indira Aerobic 1, Chandra, KPH 460 and ADV 8301, 28P09, 28S41, CO 51, DRR Dhan 50, Co-43 Sub1, CO 52, CR 1009 Sub 1 and MDU 6, CSR 46 and ADT 51
	Punjab	PR 123, Pant Basmati 2, Pusa Basmati 1609, Chandra, 27P22, HRI 180 and Pusa Basmati 1718, PR-126, Punjab Basmati-4 and Punjab Basmati-5, VNR 2111 Plus
	Bihar	CRL 22, CR Dhan 701, US 312, Sabour Surbhit, Sabour Shree, Chandra, Sukhadhan 5, DRR dhan 46, 28P67, Rajendra Nilam, MRP 5408
	All-India	VNR-2111, CO 51
Wheat	Uttar Pradesh	Phule Satwik (NIAW 3170), KRL 283, DBW 173, Pusa wheat 1612, HUW 669, AAI-W9, WB 02,
	Punjab	Phule Satwik (NIAW 3170), DBW 173, WB 02, Unnat PBW 343, PBW 1Zn
Sorghum	Tamil Nadu	CSH 38, CSH 37, K 12
Maize	Tamil Nadu	ADV 759, ADV 757, Baby corn GAYMH-1, Ladhowal Popcorn, GAPCH-21 Mahashweta, AH 7043, CO 32, CP 999, MH 9344, P 3401, HTMH 5402
Sugarcane	Tamil Nadu	CoC 13339, Sankalp
Groundnut	Tamil Nadu	Girnar 4, Girnar 5, GJG 33, VRI 8, GJG 32

Source: Various annual reports[46–48].

very near to accurate estimates. However, it is clear that yield projections in all the studies are lower than the actual yield over the study period. This deviation in projection from actual yield may be due to methodological issues or adaptation strategies adopted by farmers according to suggestions of researchers and the Government. The adaptation measures include stress-tolerant seed varieties, crop insurance, proper credit, irrigation facilities, agronomical management, modern inputs, irrigation, change in planting dates and varieties adopting crop management strategies, high input delivery, development of adverse, climate-tolerant genotypes and land-use systems, risk management through weather-based crop insurance, improved land-use policies, location-specific needs, application of biofertilizers, provision of nutrient supply, proper drainage and soil moisture conservation. These will improve the crop yield in the country and hence require more emphasis to address the climate change issues in Indian agriculture. The adaptation measures should consider long-term decision-making and introduce incentives to change the behaviour in response to climate change for proactive adaptation. The human capital needs to be strengthened through education, extension services and improvement in the decision-making capacity. However, the most vulnerable regions should adapt by diversifying their agriculture with less water-intensive crops, constructing roads and dams, and adopting farm technology like irrigation pumps, improved crop variety and harvesters[44].

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