Briefing Paper

COVID-19 recovery is a chance to climate-proof Indian farming

Key findings

- **Indian farmers are already hit by the impacts of climate change.** Increasing average annual temperatures have influenced a decline in crop yields. Unseasonal rains and heavy floods are increasing the area extent of crop damage.
- **Future climate change is definitively the biggest threat to India's agriculture**. There is increasing evidence that these changes have and will decrease land productivity and yield of all Indian major cereal crops, as well as increase yield variability. Among key crops produced, wheat and rice are the most vulnerable. Rising temperatures are the biggest risk for Indian agriculture. **In a worst-case scenario, India may become an importer of food in order to be able to feed its population.**
- Climate-induced crop failures are decreasing incomes and, in the future, annual agricultural income losses are estimated to be between 15%-18%, rising to 20%-25% for unirrigated areas. Income decline has a huge impact on farmers' livelihood, there is already an increase of indebtedness, unemployment, migration, hunger and suicides among farmers.
- **COVID-19 exposed the weaknesses of India's agriculture as the crisis hurt farms of all sizes. But there is an opportunity to advance the sector towards a "nature-based recovery**". Climate-smart agriculture can increase yield and income and reduce emissions. Investing in nature can unleash great economic benefits and business opportunities. Structural reforms, such as crop insurance and credit, can increase access to capital and boost yields. Incentivising local and shorter supply chains can increase resilience and connect farmers to markets, one of the major problems during the lockdown.

Content of this report:

Introduction

Agriculture is a key sector in India's economy, providing food for more than 1.2 billion people and employing over half of its population[1]. But this system is under threat from many fronts. Limited technical and financial resources to the reform of agricultural laws have led farmers to default on debts, limiting production. COVID-19 exposed in no uncertain terms the weaknesses inherent in India's farming sector and the inadequacies of the structures and systems that are supposed to support it. These have driven up unemployment, suicides and farmer's protests in the country.

But climate change remains the biggest threat. Over recent years, it has led to localised crop damages and failures. As both weather and climate become more unpredictable, yield variability[2] and overall production of all

[1]The sector contributes to 14% of total GDP and employs ~55% of the total workforce. India is also one of the world's largest cereal (rice, wheat, millets, barley and maize) producers. Overall, food grain production has seen constant growth, hitting a record for the third consecutive year in 2019-20.
[2] The continued use of irrigation and overuse of synthetic fertilizers to cope with these impacts will lead to more land degradation and groundwater depletion.

Indian major cereal crops will likely decline. Farmers will be increasingly reliant on government support, as their ability to increase production to meet the growing demand will be hampered by climate change. If mitigation and adaptation measures are not adopted now, food security will be threatened, especially as more than 10% of the population are already suffering from hunger.

In a post-COVID world, India has the opportunity to build a green economic recovery that improves the prospects for the country's economy and creates a climate resilient agriculture sector, including protecting the welfare of its farmers.

In this context, this report explains the main impacts of climate change in India and how they affect agriculture. It includes a summary of findings from a new literature review (2000-2020) to draw overall trends of how past and future climate change will affect yields of the most produced crops across the country. It also explains how these changes will likely exacerbate the socio-economic challenges faced by farmers. The final section presents the solutions available to the government now.

How is the changing climate worsening farmers' lives?

The climate in India is changing and its farmers are suffering from increased unpredictability, crop damage and crop failure. The main impacts of climate change related to the agriculture sector are:

1. **Temperature increases.** India's average temperature has risen by 0.7°C between 1901 and 2018. Rising temperatures affect farmers since most crops grown in India are vulnerable to warmer temperatures. As temperatures continue to rise, impacts will worsen. Additionally, it is projected that the combination of high temperature and humidity could reach dangerous levels across half of India within 20 years, making outdoor work impossible during the day.
2. **Extreme weather events.** Droughts, dry spells, heatwaves, heavy rainfall and floods are becoming larger and more frequent, causing soil damage and lower yields of rice, wheat and all food grains in India. The continued use of irrigation and overuse of synthetic fertilizers to deal with these impacts will only lead to further land degradation and groundwater depletion.
   At the same time, annual rainfall and the summer monsoon is decreasing. As 60% of farmland is rain-fed, unpredictable rainfall and its impacts on planning and production lead to decreased yields. While less frequent - yet more intense - monsoons increase the risk of crop damage and affect planting seasons, especially during the summer monsoon (July-October) when key crops ("kharif crops") are planted. Some Indian states have already announced that there is no water for irrigation due to drought, and both water insecurity and scarcity is a major developing threat.
3. **Sea level rise and groundwater salinisation.** Climate change is causing global sea level rise, which will increase the saltwater intrusion processes in coastal aquifers. All Indian coastal states are under stress of salinisation, with estimates that 6.7 million hectares in India are affected. This is most prominent on the east coast of India, mainly in Tamil Nadu and Andhra Pradesh. Alongside groundwater depletion, salinity poses further risks to water security, and it is projected that India will face severe water scarcity by 2050.

Science on the impacts of climate change in India's agriculture

There is a growing number of studies about the impacts of climate change on Indian farming. Since they use different models and look at different crops to understand climate impacts on yields in the country, it is difficult to draw overall trends of the impacts on India's farming. We carried out a thorough literature review of academic papers from 2000 to 2020 to showcase these trends. This section will summarise the findings on past and future impacts on yields of the most produced crops across India, thus helping readers to understand how climate change affects and will continue to affect India's farming.

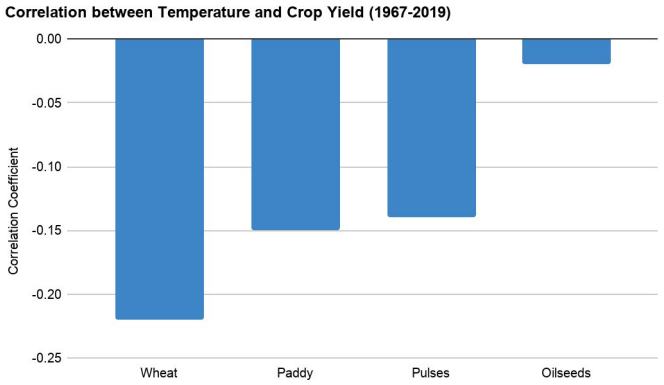
A note about definition: researchers define **food production** as the annual production of a crop in a given year (measured in tonnes). It consists of three components: **yield** is measured in tonnes per hectare per harvest; **total harvested area** is measured in hectares; and **crop intensity** describes the number of completed cropping cycles within a given year. **Food production shocks are sudden losses to food production that are most often measured in terms of yield decline** rather than the other two elements of production.

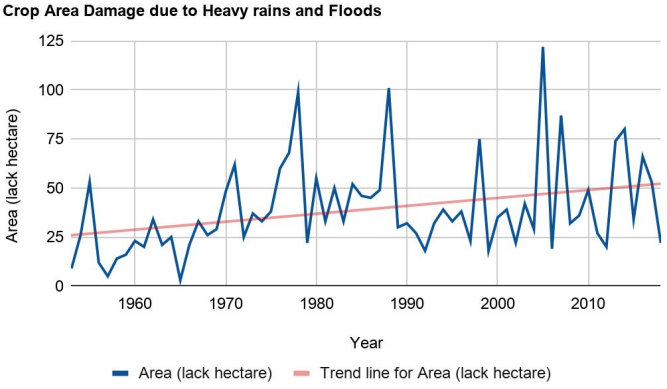
Observed impacts on key crop production

A growing body of research finds that climate change negatively[3] affects agriculture in India, with impacts varying by crop and region. Based on a collection of 50 peer-reviewed empirical and modelled studies about past impacts of climate change on Indian farming, there is increasing evidence that changes in average maximum temperature, average minimum temperature, fluctuation and extreme rainfall have and will decrease land productivity and yield of most crops, as well as increase yield variability.

Overall, studies have concluded that productivity of wheat, rice, maize, mustard, sorghum, soybeans and other non-food grain crops are likely to be lower, with estimates varying. (See Table 1 in the appendix with evidence for key crops in India.) Rice and wheat have suffered consistent losses as they are more vulnerable to higher temperatures and heatwaves than millets, which are more resistant to higher temperatures. Millet yields have increased, but the increases are likely to occur at decreasing rates as temperatures continue to rise; if temperatures keep rising, yields will start to decline. In addition to this, several studies show that higher temperatures eventually offset any yield gains from increased precipitation.

Graph 1. How has climate change affected crop yields in India?





Source: Both graphs - Reserve Bank of India - 2019-2020

***Chart 1** shows that the rise in annual average temperature in India by 1.8°C between 1997 and 2019 has likely caused a decline in crop yields. To clarify, this is a correlation effect between rising temperature and crop yields, as other elements may have been in effect as well. Even so, the chart shows the importance of taking climate change and temperature rise into account when looking at crop yields. **Chart 2** shows that India has been suffering from unseasonal rains and heavy floods that are increasing the area extent of crop damage (trend line).*

Future climate change will threaten crop yield in key producing regions

Indian agricultural lands will be affected by future changes in climate, including temperature increases, extreme weather events and sea level rise. According to the Government of India, models project that mean temperatures could rise by 4.4°C by the end of the 21st century, increasing heatwaves (by 3-4 times) and droughts (by up to 150% by 2100). Mean, extreme and inter-annual variability of rainfall will increase, and the monsoon season is projected to become more intense and to affect larger areas. Sea level is expected to rise by 20-30 cm by 2100, particularly in the north Indian Ocean. All these changes will impact **agriculturally important areas, particularly** coastal south India, central Maharashtra, the Indo-Gangetic plains and the Western Ghats.

For example, projections show that if the sea level rises by 1 m, an area over 2,000 km^2 of Indian agricultural and fisheries land will be affected. Additionally, projections show that India's east coast will be more affected by saltwater intrusion, affecting the top producers of rice, wheat and maize.

[3]In some studies, climate impacts do not always lead to yield losses. The empirical evidence about the impacts of climate change in Indian agriculture is mixed, with a recent literature review showing studies with increases or decreases in yields. These mixed results happen because these studies apply different methods (simulation and observational models), existing and projected agro-climatic conditions and climate scenarios (temperature rising by 2ºC, 3ºC, and 4ºC, increase in CO_2, and interaction of increase in temperature and CO_2, increases/decreases in rainfall). Results also vary because of the crop response to these impacts (qualitatively and quantitatively), level of agronomic management and the region and season in which the study was conducted.

These climate impacts are projected to decrease yields[4] of all Indian major cereal crops.This projection is based on a collection of 41 peer-reviewed empirical and modelled studies - 11 of the most recent studies are presented in Table 2 in the appendix. Overall, **studies show increased vulnerability and projected declines of crop yields in India from 2050, with impacts worsening by the end of the 21st century.** Towards the end of the century**,** recent research (here and here) predicts widespread declines as temperature rises and rainfall becomes more erratic.

For example, by 2100, the yield of rice and wheat - which represent ~80% of total crop production and are the main staple foods for a majority of the Indian population - can be 15% and 22% lower. Similarly, the effects on pulses are large: chickpea and pigeonpea could decline by 26% and 23%, respectively.

Impacts on India's economy and society

Climate change impacts on agriculture will have dire consequences for the economy and the social stability of India. In particular:

1. Income and job losses, leading to social instability.

Annual agricultural income losses are estimated to be between 15%-18%, rising to 20%-25% for unirrigated areas. Small and marginal farmers are set to suffer the most, particularly rice and millet farmers[5] and those in semi-arid/arid regions, as they lack access and money to invest in irrigation. Impacts on rice farmers are also particularly troubling, as rice growing provides livelihoods for more than 50 million households.

Falling income from farming increases debt, job losses, migration, suicides and protests. (See box 1). Farmers have consistently taken more debt to buy the necessary inputs for production and to deal with climate-induced crop failures. But, as many lose their incomes because of climate impacts, indebtedness increases, leading to rising unemployment and also suicides. It is predicted that India will lose 34 million jobs by 2030, mostly in the agricultural sector (p.58).

As a result of job losses, farmers are often forced to migrate. It is estimated that an average of nine million workers migrated between 2011-2016 due to the agrarian crisis. Migration also hit the poorest the most, particularly seasonal agricultural migrants who predominantly belong to the most deprived strata of the rural hierarchy. Farmers are also protesting for better conditions; demonstrations have increased by eight times between 2014-16.

These social instabilities were further exacerbated during COVID-19, as the crisis hurt farms of all sizes. The lockdown at the time of the harvest season for the rabi (winter) crop led to crops being left to rot, directly decreasing production. Milk farmers were also especially hit, leading to unrest. COVID-19 impacts lowered farmers' incomes and increased food prices, while the oversupply of labour forced people to migrate to cities, further depressing incomes and reducing purchasing power.

[4]But the effect of the warming of climate on crop yield varies across crops and regions, particularly because crops are cultivated during different seasons and using different inputs in different states.

[5]Rice and millets are largely grown by small and marginal farmers (i.e. those with holdings less than 2 hectares) and with much less irrigation, as compared to wheat, which is almost entirely irrigated and cultivated by relatively bigger farmers.

Case study: Farmers' livelihoods suffer due to climate change

Agricultural workers represent ~55% (or 263 million - p.14) of the total workers in India, with smallholder and marginal (up to 2 hectares) farmers accounting for ~86% (~125 million - p.364-366) of all farmers in India. Smallholder farmers usually need credit to buy inputs as well as to deal with crop damages caused by extreme weather. The Ministry of Agriculture & Farmers Welfare (MAFW) has many support schemes (such as the Minimum Support Price and strategies to double farmers' income). In its 2020-21 budget, 87% (or 116,490 crore) has been set on these schemes and projects, with most budget money (27%[6]) going to crop insurance and subsidies for short-term credit. These have been growing consistently (p.50) - for example, provisions to fund crop insurance have grown by 74% when comparing the 2017-18 and 2020-21 budget.[7]

These schemes have not proven to be enough to support farmers' needs. For instance, small and marginal farmers can't access institutionalized credit, with mixed reasons for why this is happening. Regional distribution is also distorted and disproportionate. Uttar Pradesh, for example, has the highest number of small farmers in the country (19% - p.366) but only 10% of total loans. Those farmers that can't access institutional credit (30% of total agricultural workers) have to borrow money from private lenders, with higher fees and shorter payback times, likely increasing debt and default.

Crop insurance exacerbates the problem, with insurance payouts rarely being approved on time to meet farmers' needs. As a result, indebtedness and bankruptcy is increasing. Nearly 52% (p.380) of agricultural households are in debt, mostly small and marginal farmers (81% of the total agricultural indebted - p.383). The government could increase disbursement of money to farmers, but this is not happening and the Finance Ministry rejected MAFW demand to increase the budget for schemes to support farmers despite the MAFW accounting for 5%[8] of India's total budget.

Climate change and the unpredictable weather it causes (see p.405-425) increase yield variability and reduce farmers' ability to plan harvests. At the same time, private insurers are dropping out from crop insurance schemes. Analysis of the higher claim ratios and lower profitability of the scheme has been partly attributed to climate change. This declining productivity raises costs and makes it hard for farmers to repay their debts, especially without access to insurance. As a result, some are taking their lives. The average death rate is higher in rural areas (or 7.1% average Crude Death Rate between 2014-16) compared to urban areas (5.1% for the same period), according to the India Census, and although suicides are a small part of it, they are very concerning.

Farmer suicides represent 7.4% of the total suicides in India and this number could increase in the future due to the projected precarity of Indian agriculture in response to climate change and the failure of social and economic systems of support. A recent study found that warming has been responsible for over 4,000 additional deaths annually across India, accounting for ~3% of annual suicides. Since 1980, 59,300 farmer suicides can be attributed to warming and the ensuing crop damage.

2. Threats to food security.

Climate-induced yield losses reduce the supply of food, making it less available and more expensive. For example, according to the Reserve Bank of India (RBI), in 2019 shifting rains and cyclones during the kharif harvest led to crop damage and supply disruptions of vegetables that pushed prices to an all-time high of 60.5% in December. If these losses happen to cereals, which are the most consumed food group in India, it will severely affect **food security** and increase **poverty and malnutrition.** Rising food prices, for example, were associated with an increased risk of malnutrition in Indian children, and a 28% increase in body wasting in 2009.

In a worst-case scenario, India may become an importer of food in order to be able to feed its population. (See box 2) Future projections show that food demand is expected to grow by 4% per annum, putting pressure on farmers to increase production. But, in a warmer climate the failure of the government to help farmers will challenge their ability to either sustain or increase production and meet the growing demand.

[6]Calculated by researchers. Refers to the percentage of insurance and short-term credit in relation to the total central schemes in the 2020-21 budget.
[7]Calculated by researchers using data from Agricultural Statistics 2018 (p.50) and the Ministry of Agriculture and Farmers Welfare Budget 2020-21.
[8]Calculated by researchers.

The likely solution would be to import food - indeed, projections of a 2°C warming by the 2050s shows that India may need to import more than twice the amount of food grain than would be required without climate change.

Box 2. Climate extremes, food production shocks and the risk of a hunger crisis

Apart from long-term and continuous changes, climate change can also cause abrupt and erratic **extreme weather events that cause major yield losses (e.g heatwaves, droughts, cyclone storms).** Under normal climate conditions, crop yield losses affect a small share of global production and can be compensated by trade and grain storage. But, if they occur in two or more key regions of production and are not compensated by trade or storage, multiple breadbasket failures can occur and present a systemic threat to food security. Shocks like these can also have cascading effects, such as food price spikes.

For India, these climate extremes not only mean a gradual decline of crop production, but also increased volatility of production and shocks like crop failures. They are a huge threat to food security, given that the country already has over 190 million people suffering from hunger. Changes in climate threaten a reduction of both availability of and access to food, especially among the poor, which can further lead to political unrest, hunger and migration. Alongside the COVID-19 pandemic, which is already predicted to cause widespread famine and could trigger a mass movement of refugees, these future unpredictable climate shocks could provoke a hunger and migration crisis in India.

3. Big burdens on the government budget and India's financial system.

The Indian government already spends a lot of money on supporting its farmers and maintaining stable food prices for consumers (through food subsidies and trade regulations), but it is failing to do so adequately (see previous box). As farmers suffer more production losses, government expenditures will likely increase. It is predicted that climate change impacts on agriculture will lead to a 1.5% loss in India's GDP, while the Indian Central Bank (RBI) predicts that around 3% of the GDP will be spent on countering them. In 2020, the RBI recognised that "the issue of climate change needs to be taken seriously".

India's financial system will also suffer from climate change impacts on agriculture. It accounts for 12.6% (USD 154 billion) of the overall credit of banks, and is thus a source of credit for farms. But as crop losses lead to political pressure on banks to write off or offer loans at higher interest rates to already indebted farmers, it is safe to conclude that the system is heading towards a default.

COVID-19 pandemic recovery must "climate-proof" the Indian agricultural sector

COVID-19 exposed the weaknesses of India's agriculture, and climate change will only increase these risks. In this context, the recovery packages to the pandemic could be leveraged to integrate climate-smart agriculture systems in India, an approach that takes into consideration the social, economic, and environmental context where it will be applied (see box below). Key among these policies are:

1. Increasing incentives for sustainable agriculture.

There are several adaptation strategies that can be enacted to minimise the impacts of climate change on the agriculture sector. Sustainable agriculture, for example, can help farmers minimize production losses while improving incomes. Climate-smart agriculture[9] can significantly increase yield and income and reduce emissions. Among these, tillage practices are interesting for rice and wheat production in India: estimates show this can increase yields by 5-37%, income by 28-40%, water-use efficiency by 30%, while reducing greenhouse gas (GHG) emissions by 16-25%. In fact, India is already adopting some of these interventions.

Similarly, agroforestry has been practiced by rich farmers for 6-8 years in south India. Using different irrigation systems can also help farmers cope with changes in rainfall and saltwater intrusion while reducing their water consumption. For example, drip irrigation (p.45) can reduce the water consumption of sugarcane growing by 44% and grapes by 37%, while increasing the yields by up to 29%. Integrated watershed management, implemented in semi-arid, rain-fed agrarian landscapes in India, also has shown to help mitigate drought impacts and to raise productivity and incomes.

[9]Includes several practices such as crop diversification, conservation agriculture (minimum tillage, residue retention, laser levelling), improved varieties, weather-based insurance, agro-advisory services, precision agriculture and agroforestry.

Box 3. Climate-smart agriculture and nature-based recovery

According to the Food and Agriculture Organisation, climate-smart agriculture (CSA) aims to develop the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change. It is composed of three main pillars: "sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gases emissions, where possible" (p.ix). The CSA approach not only makes agriculture more resilient but also strengthens livelihoods and food security, especially of smallholders. This happens by improving the management and use of natural resources and adopting appropriate methods and technologies for the production, processing and marketing of agricultural goods.

There is increasing international recognition that the post-COVID world needs to incorporate more nature-based recovery, especially for the agriculture and agroforestry sectors. These solutions can unleash huge economic, employment and business opportunities. A recent report by the Food and Land Use Coalition found that changing the way we farm and produce food could release USD4.5 trillion a year in new business opportunities globally by 2030. The World Economic Forum's New Nature Economy report found that investing in the food, land and ocean sector can create 191m new jobs globally by 2030. Other estimates show that restoring 160 million hectares of degraded agricultural land could generate USD 84 billion in annual economic benefits, boost farmers' incomes (by USD 35 billion to USD 40 billion per year) and improve food security (additional food for nearly 200 million people).

2. Scaling-up the digitisation of the farming sector.

Adopting digital technologies and working with agri-tech start-ups can help farmers increase production and minimise environmental impacts. Innovative start-ups are using digital technologies to provide better market information and risk management in agriculture, as well as to improve smallholder farmers' income, while also having positive environmental and nutritional benefits. Digital loans are also speeding up credit delivery, making credit more accessible to small and marginal farmers.

Government policies can facilitate farmers' access to digital technology. For instance, the eNational Agriculture Market (eNAM) is a virtual platform where smallholder farmers can sell their produce, thus eliminating intermediaries from food value chains. Using "technologies alongside incentivising the logistical role played by e-commerce and delivery companies" can help farmers both access market channels and increase food availability to consumers. For example, while markets were shut during COVID-19, many farmers began receiving orders using WhatsApp and delivering the produce directly to peoples' doorsteps.

3. Reforming agri-food policies to support farmers and tackle climate change.

The government should **create a fiscal stimulus that actually supports farmers.** Structural reforms, such as crop insurance and credit, can increase access to capital and boost yields. Research by the International Food Policy Research Institute (IFPRI) showed that access to credit has increased Indian farmers' income substantially and has significantly raised yields of major staple crops. The government should also create social safety nets to support agriculture and migrant labourers during crises. But changes like these also need to come **with conditions to apply sustainable practices** (current support measures do not have sustainability considerations) in order to help farmers mitigate and adapt to climate change and improve food security.

Policies and subsidies that are skewed in favour of staple crops, like rice and wheat, can be reformulated to increase support for climate-resilient and nutritious cereals, like sorghum and other millets. This would lead to a variety of crops being grown, which would reduce land degradation while also improving food security via increased and diversified food options. Incentivising local and shorter supply chains can also help to increase resilience, while connecting farmers to markets - this was one of the major problems during the lockdown. For other solutions see here and here.

Conclusion

Agriculture is a key sector for livelihood and employment In India, but climate change is and will continue to threaten the sustainability of the system. In a warmer world, producing more food for India's growing population will be a big challenge in the absence of adaptation and mitigation strategies. The Indian government should use the COVID-19 recovery to climate-proof indian farming, by setting structural reforms and supporting farmers in

adopting climate-smart practices that can increase yield and income and reduce emissions. Only by widely adopting these measures can India create a resilient food system.

Appendix

Table 1. Key producing regions and past impacts of climate change on production

*This table includes empirical and modelling studies on the **past impacts of climate change** (temperature and rainfall) on crop yields in India. It includes studies* on rice, wheat and pearl/sorghum millets only, as most studies focus on these key crops in India. *Please see the spreadsheet (Sheet 2) for further comments and limitations from the studies (22 from 51 studies selected).*

Key crop	Main production regions (% national production) and total production	Production impacts
Rice	West Bengal (13.3%) Punjab (11.9%) Uttar Pradesh (11.8%) National production (2017-18): 112.91 Mt	At state and district level, analyses of long-term production data suggest a decreasing trend for rice yields. Between 1966–2002, **kharif rice yields could have been 5.67% higher** in the absence of climate change.
Wheat	Uttar Pradesh (32.0%) Punjab (17.9%) Madhya Pradesh (16.0%) National production (2017-18): 99.7 Mt	Looking at data from 200 districts, which account for over 90% of Indian wheat production, it is estimated that **wheat yields were 5.2% lower** than they would have been if temperatures had not increased during 1981–2009. In 2010, due to climate and pollutant emissions, the main wheat and rice producing states Uttar Pradesh and Uttaranchal lost ~50% of their wheat yields.
Bajra (pearl millet)	Rajasthan: 41.1% Uttar Pradesh: 19.7% Gujarat: 10.1% National production (2017-18): 9.13 Mt	So far, studies[10] show that both millets had positive responses as temperature increases. Bjara has been less affected by rainfall and temperature, meaning that it tolerates higher heat than the jowar crop. Similarly, higher temperatures can be beneficial for bjara yields but have a decreasing beneficial effect as temperature increases. For jowar, as temperatures increase, the yield declines but at a decreasing rate.
Jowar (sorghum millet)	Maharashtra: 36.5% Karnataka: 22.9% Madhya Pradesh: 11.5% National production (2017-18): 4.95 Mt	

Table 2. Estimates of the future impacts of climate change on India's agriculture

*This table includes most recent (2014-2020) empirical and modelling studies on the **future impacts of changes of climate** (temperature and rainfall) on crop yields in India. Based* on the literature review, 10 of 41 studies focus on *these crops. Please see the spreadsheet (Sheet 2) for further comments and limitations from the studies.*

Regions	Crops	Future period	Key finding	Source
Agroclimatic zones	Rice	2020s: *2006-2035* 2050s: *2036-2065* 2080s: *2066-2095*	The impact on rice yield at country level, as projected based on 32 GCM-RCP combinations, may vary from 1.2-8.8%, 0.7-12.6% and −2.9 -17.8% due to the combined impact of precipitation change and temperature rise in the 2020s, 2050s and 2080s, respectively.	Climate change induced impact and uncertainty of rice yield of agro-ecological zones of India (2019)
India	Sorghum, pearl millet	2071-98	• The yield vulnerability is higher towards the period 2071-98 compared to 2021-50. • The average yield impact is about 218 kg/ha for sorghum and 274 kg/ha for pearl millet. • Analysis indicated no significant yield vulnerability for the mid-century period, but the yield vulnerability showed considerable variability across districts.	Yield vulnerability of sorghum and pearl millet to climate change in India (2019)

[10] https://iopscience.iop.org/article/10.1088/1748-9326/ab22db/pdf; https://ideas.repec.org/p/hit/hitcei/2015-9.html; https://www.sciencedirect.com/science/article/pii/S0048969717314067; https://www.worldscientific.com/doi/abs/10.1142/S2010007814500018 ; https://link.springer.com/article/10.1007%2Fs11356-018-3925-7

India	Potato, groundnut, sesame and cotton	1% increase in climatic variables	• Cropped area of groundnut and sesame crops is projected to decline by 13.87% and 23.50%, respectively, due to a 1% increase in climatic variables (rainfall, average maximum and average minimum temperature). • Production of groundnut and cotton crops is projected to decline by 9.83% and 41.09%, respectively, due to a 1% increase in climatic variables. • Yield of potato, groundnut, sesame and cotton crops is projected to declined by 3.71%, 10.31%, 4.51% and 7.20%, respectively, due to a 1% increase in climatic variables.	Effect of climatic factors on cash crop farming in India: An application of Cobb-Douglas production function model (2017)
India	15 crops	2040, 2060, 2080 and 2100	• Annual average maximum and minimum temperature have a negative effect on land productivity. • Annual rainfall has a positive impact. But the positive effect of rainfall cannot compensate for the loss of land productivity due to increased temperatures. • Estimates are that climate change impact on Indian agriculture would be largely driven by change in temperature. • Climate change would decrease land productivity by 14.72%, 22.98%, 31.23% and 48.63% by the years 2040, 2060, 2080 and 2100, respectively. These results are predicted by assuming that rainfall and surface temperature would increase.	Assessing the Impacts of Climate Change on Land Productivity in Indian Crop Agriculture: An Evidence from Panel Data Analysis (2016)
India	Rice, sorghum	End of the 21st century	• As temperature and rainfall increase, crop yield initially increases up to a threshold level, and then decreases. • Following the RegCM4 projections that observed warming and anomalies in rainfall will continue, this could result in a significant loss in crop productivity. Projections suggest that there may be a 10% decline in rice yield and a 9% decline in sorghum yield by the end of the 21st century relative to average yields during 1971-2009.	Impact of Climate Change on Yield of MajorFood Crops in Tamil Nadu, India (2015)
India	Rice, wheat, sorghum, maize, barley, chickpea, pigeonpea, groundnut and rapeseed, mustard	2035, 2065 and 2100	• A 1°C rise in the maximum temperature in the kharif season reduces the yield of rice, sorghum and pigeonpea by 11-12%, and of maize and groundnut by around 9%. • By 2100, the rice yield will be lower by 15%, wheat yield by 22%. Coarse cereals will be less affected. Pulses will be affected more than cereals. Chickpea yields will be 26% lower. And pigeonpea yields will decline by 23%. • In the short-run, climate impacts will not be so severe.	Impact of Climate Change on Yields of Major FoodCrops in India: Implications for Food Security (2014)
Case-study (Amritsar, Ludhiana, Hisar, Ambala, Modipuram and Kanpu)	Rice	2010, 2030, 2050, 2070, 2090	• **Overall projection of a reduction in productivity of rice crop in all main rice producing states in India.** • The percentage change of average yields between 2010-2090 scenarios is: lower by 3% in Amritsar; increase by 1% in Ludhiana; lower by 19% in Hisar; lower by 17% in Ambala, lower by 12% in Modipuram; lower by 7% in Kanpur. (Calculated based on table 2 of the paper.)	Impact of Projected Climate Change on Rice (Oryzasativa L.) Yield Using CERES-Rice Model in DifferentAgroclimatic Zones of India (2017)
Case-study (Hisar, Jodhpur, Bikaner, Jaipur, Aurangabad and Bijapur)	Pearl millet	2050	• **Drought and heat tolerance in pearl millet increases yields** under climate change in both the arid and semi-arid tropical climates, with greater benefit in relatively hotter environments. • Yield benefits of heat tolerance substantially increased under climate change at most locations, having the greatest effects at Bikaner (17%). No yield advantage from heat tolerance in the Aurangabad and Bijapur locations due to low temperature regimes.	An assessment of yield gains under climate change due to genetic modification of pearl millet (2017)

Case-study (Indo-Gangetic Basin)	Potato	2020: *2010-2039* 2050: *2040-2069* 2080: *2070-2099*	● **Climate change is projected to reduce potato yields by ~2.5%, ~6% and ~11% in the IGP region in 2020 (2010-2039), 2050 (2040-2069) and 2080 (2070-2099), respectively.** ● Change in planting time is the single most important adaptation option. This together with an improved variety of, or additional, nitrogen will see positive gains of ~5% in 2050. ● Intra-regional differences in the impact of climate change and adaptation gains are projected: Positive impact in northwestern IGP; gains in Central IGP with adaptation; and yield loss in eastern IGP even with adaptation.	Assessment of impact of climate change on potato and potential adaptation gains in the Indo Gangetic Plains of India (2015)
Case-study (Eastern India)	Rice	8 climate scenarios	● Models showed different levels of yield increase with a **clear reduction in yield under rain-fed rice** as compared to irrigated rice. ● Rice yields are impacted at all locations; Ranchi had maximum losses in terms of yield because of its rain-fed ecosystem. ● Increased CO_2 concentrations increased rice yields in all the locations except Ranchi.	Predicting Irrigated and Rainfed Rice Yield UnderProjected Climate Change Scenarios in the EasternRegion of India (2015)