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Climate Change and Its Impact on Sustainable Agricultural Development

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Abstract

Agriculture is the sector most directly dependent on climate, and it is also one of the sectors most exposed to the effects of climate change. Rising temperature, changing rainfall, heat waves, droughts and floods affect crop yield, water availability, soil health and farm income, and thereby threaten the goal of sustainable agricultural development. This paper examines the impact of climate change on agriculture with special reference to India, using secondary data from the Ministry of Agriculture and Farmers Welfare, the Reserve Bank of India, and peer-reviewed research. Three comparison tables are prepared: crop-group wise production of foodgrains from 2019-20 to 2023-24, year-on-year growth of different crop groups to identify climate-sensitive fluctuations, and a comparison of estimated yield losses per degree of warming in major crops as reported by global studies. The analysis shows that foodgrain production has increased by nearly 12 per cent in four years, but the growth is uneven. Wheat output fell in 2021-22, and pulses output declined in both 2022-23 and 2023-24, with the Ministry attributing the latter fall to drought-like conditions and a long dry spell. Global studies indicate that each degree of warming can reduce the yield of wheat by 4 to 6 per cent and of maize by about 7 per cent, unless adaptation measures are adopted. The paper concludes that sustainable agricultural development under changing climate requires climate-resilient crop varieties, efficient water use, soil conservation, crop diversification, weather-based advisory services and supportive policy.

Keywords: Climate Change, Sustainable Agriculture, Crop Yield, Food Security, Adaptation, Climate-Smart Agriculture, India

Introduction

Climate change means a long-term shift in the average and variability of temperature, rainfall and other weather conditions, which is now caused mainly by human activities that increase the concentration of greenhouse gases in the atmosphere. The Intergovernmental Panel on Climate Change has reported that human-caused warming has already affected weather and climate extremes in every region of the world, and that agricultural productivity growth has been reduced by climate change in many regions since the middle of the last century (IPCC 720). For India, the national assessment of climate change reports that the average temperature of the country rose by about 0.7 degree Celsius between 1901 and 2018, and that the frequency of heat waves and of heavy rainfall events has increased (Krishnan et al. 6).

The link between climate and crops is physical and direct. Crops need a suitable range of temperature, enough water and sunlight, and a stable length of growing season. High temperature during critical stages such as flowering and grain filling shortens the crop cycle and lowers yield, while irregular rainfall leads to moisture stress or waterlogging. Schlenker and Roberts showed in the case of American crops that yields rise gradually with temperature up to a threshold and fall sharply

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above it, which means that extreme heat is more damaging than a small rise in the average (Schlenker and Roberts 15595).

Agriculture remains the main source of livelihood for nearly half of India's workforce, although its share in national output is less than one-fifth. A large part of the cultivated area is rain-fed, farm holdings are small, and many farmers have limited access to irrigation, credit, insurance and advisory services. These features make Indian agriculture highly sensitive to the monsoon and to temperature extremes. Kumar and Parikh estimated, using farm-level data, that a rise of two degrees Celsius in temperature together with a seven per cent increase in rainfall would reduce net farm revenue in India by about 8.4 per cent (Kumar and Parikh 151). Auffhammer, Ramanathan and Vincent reported that rice yield in India is adversely affected by increase in temperature and by the variability of monsoon rainfall (Auffhammer et al. 415). A review of Indian studies by Mall and co-authors concluded that climate change will affect crop duration, water requirement and yield of major crops, with significant regional differences (Mall et al. 450).

The vulnerability is not uniform. The northern plains, which produce wheat and rice, are exposed to terminal heat stress and groundwater depletion; the semi-arid regions face drought and variable rainfall; coastal regions face cyclones and salinity; and the Himalayan region faces changes in snow and glacier melt. Guiteras found that the impact of climate change on Indian agriculture is negative and grows over time if farmers do not adapt (Guiteras 4).

Sustainable agricultural development means producing enough food, fibre and income for the present generation without damaging the natural resources on which future production depends. Pretty described agricultural sustainability as the use of farming practices that make the best use of natural processes and ecosystem services, and that do not cause serious damage to land, water and biodiversity (Pretty 447). Tilman and colleagues warned that intensive production, with heavy use of fertilizer, pesticide and irrigation, has raised yields but has also caused soil degradation, water pollution and loss of biodiversity, so that future growth must come from more efficient and less harmful methods (Tilman et al. 672).

Climate change makes this balance more difficult. Wheeler and von Braun explained that climate change affects all four dimensions of food security, namely availability, access, utilisation and stability, and that poor and rural populations are the most affected (Wheeler and von Braun 509). The Food and Agriculture Organization expects global demand for food to rise by about half by 2050, which means that agriculture has to produce more under harsher climate conditions (FAO 11). Lipper and co-authors proposed climate-smart agriculture as an approach with three objectives: to raise productivity and income in a sustainable way, to adapt and build resilience, and to reduce or remove greenhouse gas emissions where possible (Lipper et al. 1068).

Objectives

1. To explain the channels through which climate change affects agriculture.
2. To analyse recent trends in foodgrain production in India.
3. To compare fluctuations across different crop groups and identify signs of climate stress.
4. To compare the estimated impact of warming on major crops based on global studies.

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Review of Literature

The literature is reviewed under three heads: global impacts of climate change on crops, impacts on Indian agriculture, and adaptation and sustainability.

Global impacts. Rosenzweig and Parry used crop and economic models to examine the effect of climate change on world food supply and found that the global change in production would be modest, but that developing countries would be more adversely affected and that the number of people at risk of hunger would rise (Rosenzweig and Parry 135). Parry and co-authors reached a similar conclusion for different emission scenarios, noting that the gap between developed and developing regions would widen (Parry et al. 60). Lobell, Schlenker and Costa-Roberts analysed global data since 1980 and found that warming trends had already reduced global wheat production by about 5.5 per cent and maize by about 3.8 per cent compared with a situation of no climate trend, while the net effect on rice and soybean was small (Lobell et al. 617). Zhao and co-authors combined four independent methods and estimated that each degree of global warming would reduce global yields of wheat by 6.0 per cent, rice by 3.2 per cent, maize by 7.4 per cent and soybean by 3.1 per cent (Zhao et al. 9326). Asseng and colleagues reported from a large set of crop models that each degree of warming reduces global wheat production by between 4.1 and 6.4 per cent (Asseng et al. 143). The fifth assessment report of the IPCC concluded that negative impacts of climate change on crop yield have been more common than positive impacts (Porter et al. 488).

Impacts on Indian agriculture. Aggarwal summarised that rising temperature and changes in rainfall would shorten the duration of crops and reduce the yield of wheat and other crops in India, while higher carbon dioxide may partly offset the loss in some crops (Aggarwal 912). Kumar and Parikh estimated the sensitivity of farm incomes to temperature and rainfall (Kumar and Parikh 151). Auffhammer et al. connected monsoon variability with rice yield (Auffhammer et al. 415), and Guiteras found that the damage increases with time (Guiteras 4). Mall et al. noted the regional variation in effects across crops (Mall et al. 450).

Adaptation and sustainability. Smit and Skinner classified adaptation options in agriculture into technological developments, government programmes and insurance, farm production practices and farm financial management (Smit and Skinner 90). Challinor and colleagues carried out a meta-analysis of crop yield under climate change and adaptation and found that adaptation, such as changing varieties and planting dates, raises yields by about seven to fifteen per cent, although it may not fully offset the losses at higher warming (Challinor et al. 289). Lal showed that soil carbon sequestration can improve soil quality and food security while helping to reduce atmospheric carbon dioxide (Lal 1623). Lipper et al. proposed climate-smart agriculture as an integrated approach (Lipper et al. 1068). To summarise, the literature shows that warming reduces yield of major crops, that developing countries are more vulnerable, and that adaptation can reduce losses. Few studies compare recent production trends of Indian crop groups with the findings of global yield studies, and this comparison is attempted here.

Research Methodology

The study is descriptive and analytical and uses only secondary data. Data on production of foodgrains by crop group for the years 2019-20 to 2023-24 were taken from Table 17 of the Handbook

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of Statistics on the Indian Economy 2024-25 published by the Reserve Bank of India, which compiles the official figures of the Ministry of Agriculture and Farmers Welfare. Explanations for the fluctuation in particular years were taken from the statements of the Ministry. The estimates of yield loss per degree of warming were collected from the global studies cited in the references. Year-on-year growth rates and the growth over the base year 2019-20 were calculated. The data are rounded, and the latest figures should be checked on the website of the Ministry before reuse.

The study has some limitations. Production data are the result of area, yield, input use and policy as well as climate, so the change in production cannot be attributed entirely to climate. The Indian data are for the country as a whole and hide regional differences. The estimates of global yield loss are averages from models and studies in different regions, and they should be read as indicators of the direction and approximate size of the effect and not as forecasts for any one Indian state.

Data Analysis and Discussion

Table 1 shows the production of the main groups of foodgrains in India for five years and compares the level in 2023-24 with the base year 2019-20.

Table 1: Crop-group wise Production of Foodgrains in India (2019-20 to 2023-24), Million Tonnes

Crop Group	2019-20	2020-21	2021-22	2022-23	2023-24	Growth, 2019-20 to 2023-24 (%)
Rice	118.87	124.37	129.47	135.76	137.83	16
Wheat	107.86	109.59	107.74	110.55	113.29	5
Coarse cereals	47.75	51.32	51.1	57.32	56.94	19.2
Pulses	23.03	25.46	27.3	26.06	24.25	5.3
Total foodgrains	297.5	310.74	315.62	329.69	332.3	11.7

Source: Reserve Bank of India, Handbook of Statistics on the Indian Economy 2024-25, Table 17 (data of the Ministry of Agriculture and Farmers Welfare); converted from lakh tonnes, growth calculated by the author.

Total foodgrain production increased by about 11.7 per cent in four years, from 297.50 to 332.30 million tonnes (Reserve Bank of India 48). The growth was led by coarse cereals and rice, which increased by 19.2 per cent and 16.0 per cent. Wheat and pulses, in contrast, increased by only about five per cent. Rice and wheat together account for about three-fourths of total production, so the food security of the country depends strongly on how these two crops respond to climate stress. The increase in total production shows the effect of better seed, irrigation and procurement support, and

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it should not be read as proof that climate change has had no effect. The next section looks at the yearly fluctuations, which are a better indicator of weather-related stress.

Year-on-Year Fluctuation in Crop Groups

Climate stress is more visible in sudden fall or slowdown in output than in the long-run average. Table 2 compares the year-on-year growth rates of the crop groups and shows the range between the best and the worst year for each group.

Table 2: Comparison of Year-on-Year Growth (%) in Production of Crop Groups

Crop Group	2020-21	2021-22	2022-23	2023-24	Range between Best and Worst Year (percentage points)
Rice	4.6	4.1	4.9	1.5	3.4
Wheat	1.6	-1.7	2.6	2.5	4.3
Coarse cereals	7.5	-0.4	12.2	-0.7	12.9
Pulses	10.6	7.2	-4.5	-6.9	17.5
Total foodgrains	4.5	1.6	4.5	0.8	3.7

Source: Calculated by the author from Table 1.

The comparison shows that rice and wheat were comparatively stable, while coarse cereals and pulses were highly variable. The range between the best and the worst year was only 3.4 percentage points for rice and 4.3 for wheat, but it was 12.9 for coarse cereals and 17.5 for pulses. Many pulses and coarse cereals are grown on rain-fed land, so they respond sharply to rainfall. The Ministry of Agriculture and Farmers Welfare attributed the decline in pulses, coarse cereals, soybean and cotton in 2023-24 to drought-like conditions in the southern states, including Maharashtra, and a prolonged dry spell in August, particularly in Rajasthan (Ministry of Agriculture and Farmers Welfare 1). The two successive falls in pulses, of 4.5 per cent and 6.9 per cent, have reduced pulses output in 2023-24 to a level only about five per cent above 2019-20, and this is important because India depends on pulses for protein in vegetarian diets. Wheat output declined by 1.7 per cent in 2021-22, the only fall in wheat in the period, which coincides with the early and intense heat reported in north India in March of that year, when the crop was at the grain-filling stage; this is consistent with the findings on heat stress in the global literature (Asseng et al. 143; Schlenker and Roberts 15595). Total foodgrain growth slowed to only 0.8 per cent in 2023-24, the lowest in the period. Since irrigation, inputs and area also change from year to year, these patterns indicate climate sensitivity but do not prove a single cause. Ray and co-authors similarly found that climate variation explains a substantial part of the variability of global crop yields (Ray et al. 8).

Comparison of Estimated Yield Loss from Warming in Major Crops

The national data cannot show how large the effect of warming will be, so Table 3 compares the estimates of three important global studies. The figures show the percentage change in global yield for each degree Celsius of warming, or for observed warming trends.

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Table 3: Comparison of Estimated Impact of Warming on Global Yield of Major Crops

Crop	Zhao et al.: Change per 1°C Warming (%)	Asseng et al.: Change per 1°C Warming (%)	Lobell et al.: Effect of 1980- 2008 Warming Trend (%)	Sensitivity Rank (Zhao et al.)
Maize	-7.4	Not estimated	-3.8	1 (most sensitive)
Wheat	-6	-4.1 to -6.4	-5.5	2
Rice	-3.2	Not estimated	Small net effect	3
Soybean	-3.1	Not estimated	Small net effect	4

Source: Compiled by the author from Zhao et al. (page 9326), Asseng et al. (page 143) and Lobell et al. (page 617).

Table 3 shows that the three studies agree on the direction and broadly on the size of the effect for wheat. The estimates for wheat lie between about four and six per cent for each degree of warming, and the observed loss of 5.5 per cent over the past decades is within the same range (Zhao et al. 9326; Asseng et al. 143; Lobell et al. 617). Maize is the most sensitive crop and rice and soybean are the least sensitive according to Zhao et al. These results have two implications for India. First, wheat, which is the second major staple and is grown in the cool season, is exposed to losses if the winter warms or if the heat arrives early. Second, since rice is relatively less sensitive to a given rise in average temperature, its losses are more likely to come from water shortage, monsoon variability and extreme events (Auffhammer et al. 415). The size of the loss can be reduced by adaptation, as Challinor et al. found that changes in variety and planting date raise yields by about seven to fifteen per cent (Challinor et al. 289). Adaptation is therefore not a luxury but a necessary part of sustainable agricultural development.

Major Findings

The study offers the following findings. First, India's foodgrain production rose by about 11.7 per cent between 2019-20 and 2023-24, led by rice and coarse cereals, but the growth in wheat and pulses was only about five per cent. Second, rice and wheat were relatively stable, whereas pulses and coarse cereals showed wide yearly fluctuation, which is typical of rain-fed crops under rainfall variability. Third, wheat production fell in 2021-22 and pulses output fell in 2022-23 and 2023-24, the latter being linked by the Ministry to drought-like conditions and a long dry spell. Fourth, global studies estimate that each degree of warming reduces wheat yield by about four to six per cent and maize yield by about seven per cent, while rice and soybean are less sensitive. Fifth, adaptation measures can recover a significant part of the loss, so the net effect of climate change on agriculture depends on how well farmers and institutions adapt.

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Suggestions

Agricultural research should develop and promote heat-tolerant, drought-tolerant and short-duration varieties of wheat, rice, pulses and millets, and the seed system should make them available to small farmers. Water use efficiency should be improved through micro-irrigation, laser land levelling, crop scheduling and the revival of local water bodies, particularly in regions with falling groundwater. Crop diversification toward millets and pulses in suitable areas can reduce the risk and the demand for water. Soil health should be strengthened by organic matter, conservation tillage and balanced fertilizer use, which also help to store carbon (Lal 1623).

Weather-based advisory, early warning and crop insurance should be made easily accessible to farmers, with information in local languages. Policy should support climate-smart practices through incentives and extension, and should monitor not only production but also the use of natural resources, in line with the idea of sustainable agriculture (Lipper et al. 1068; Pretty 447). Future research should connect district-level climate data with crop yield to measure the effect of climate on Indian agriculture more precisely.

Conclusion

Climate change is a serious and growing challenge for sustainable agricultural development. The Indian data show that total foodgrain production has increased, but that the growth is uneven and that rain-fed crops such as pulses and coarse cereals, and heat-sensitive crops such as wheat, show clear signs of weather-related stress.

Global studies indicate that warming can reduce the yield of major crops by several per cent for each degree of rise, although adaptation can recover a part of the loss. Sustainable agricultural development under climate change therefore requires a combination of resilient crop varieties, efficient water and soil management, diversified farming systems, timely information and supportive policy. If these measures are adopted widely, agriculture can continue to provide food, income and employment while using natural resources responsibly, and it can contribute to climate mitigation as well.

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