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Impact of Climate Change on Crop Yields and Adaptation Strategies in Madhya Pradesh and Rajasthan

Dr. Hrideshwer Gupta [1 *]

1. D. Litt. Research Scholar, Bir Tikendrajit University, Manipur, India
h.gupta@live.com

Abstract: This research looks at how farmers in Madhya Pradesh and Rajasthan have adapted to climate change and how it has affected their agricultural output. The research evaluated the impact of climate change on three potato cultivars Kufri Badshah, Kufri Jyoti, and Kufri Pukhraj across 38 districts in Madhya Pradesh using the WOFOST agricultural growth simulation model. Results indicate a significant decline in yield by 2055 under projected climate scenarios. In Rajasthan, analysis of historical data revealed region-specific declines in both kharif and rabi crop productivity. Farmer surveys in Bikaner showed that many are changing their farming methods, like planting at different times (87%), using different types of crops (86%), and using more water for irrigation (83%), mainly because they believe it will help their finances. The findings underscore the urgency of developing climate-resilient agricultural systems and informed policy interventions tailored to local conditions.

Keywords: Crop Growth, Agriculture, Climate change, Adaptation, Farming

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INTRODUCTION

The true risks of climate change and unpredictability to agriculture and food security. The agricultural crops are being hit hard by the unpredictable rainfall patterns and extreme weather occurrences". One of the most difficult and multifaceted problems affecting agricultural development on a global scale is climate change. Climate change is having a devastating effect on people's ability to make a living, the availability of food, people's health, economic possibilities, and even humanity's very existence, particularly in emerging nations like India. Warm weather with little rain is predicted to become much more common as a result of global warming.

There are many pressures, both sectorial and non-sectarian, on India's agricultural sector at the same time. The dramatic weather fluctuations that have grown commonplace throughout the years make these difficulties much more formidable. In order to provide food and nutritional security for its expanding population, India is increasingly worried about climate change. Though it has an effect all around the world, nations like India are particularly at risk since so many people there work in agriculture (SV Sonune and SB Mane 2018). The Ratlam region saw the start of NICRA (National Innovations on Climate Resilient Agriculture) programs in 2015 and 2016. The initiative had its start in February 2011.

By demonstrating new technologies and conducting strategic research, this initiative hopes to make India's agricultural sector more resistant to the effects of climate change. Amba hamlet in Piploda Tahsil, Ratlam district, is set to host an integrated package of proven technologies as part of the NICRA project's technology demonstrations component (TDC). The goal of this adaptation is to lessen the impact of climatic unpredictability on the agricultural and production system. Challenges to sustainable agricultural output are posed by the combination of rising temperatures and the possibility of changes in the geographical and temporal patterns of rainfall. There are direct and indirect effects of climate change on agricultural production.

The issue of climate change is now one of the most critical global concerns. Temperature and precipitation are two examples of meteorological components for which long-term averages have shown substantial shifts. There has been mounting evidence over the last few decades that increased human activities have changed the chemical makeup of the Earth's atmosphere, leading to noticeable shifts in the global temperature.

By implementing adaptation strategies, we can lessen the impact of climate change on some areas, which threaten agricultural production and food safety. To create appropriate adaptations, which in turn shape farmers' readiness to climatic-induced hazards, Recognizing the risks associated with climate change and how farmers see them is crucial. It is important to remember that if people don't understand climate change and the hazards it poses, they could not adapt enough, which might make farms even more vulnerable to livelihood shocks. Consequently, the purpose of this article is to seek out local opinions in the Bikaner district of Rajasthan about the effects of climate change, the adaptation strategies put in place to deal with these consequences, and the obstacles that hinder successful adaptation.

LITERATURE REVIEW

Mohapatra, Geetilaxmi et.al. (2022). Due to the climatic dependence of agricultural goods and production, the worldwide problem of climate change is causing undue suffering in this industry. The perspective of farming families on climate change and their adaptation strategies is examined in this study. Primary data for this study comes from an investigation into the semi-arid and dry areas of Rajasthan, India, using a purposeful random sampling method. The research uses logistic regression to find out what factors influence people's views on climate change and their plans to adapt, and it builds a livelihood vulnerability index to show how vulnerable families are, with an emphasis on their potential to adapt. Just 534 out of 600 homes in the study think the climate is changing over the long term. Farm ponds, crop rotation, mixed cropping, and crop diversification are some of the adaptation measures used by farmers.

Dupare, B. et.al. (2020). While soybeans have only been cultivated commercially in Central India for the last fifty years, beginning in the 1970s, they have quickly become an important kharif crop for farmers in this region. Both the acreage and output of the crop have increased significantly so far, with small and marginal farmers being the primary growers. Madhya Pradesh, the soy state, accounts for around 56% of India's total soybean land and output, making it the country's top soybean producer. On the other hand, national soybean productivity has been about 1,000 kg/ha over the last decade. The crop is cultivated in rainfed circumstances; therefore, the climate is a major factor in the causes. Previous research has also shown that some climatic variables are changing, such as the frequency with which extended dry spells occur and the prevalence of pest and disease complexes. Research was carried out to get insight into how local farmers perceive climate change and its potential effects on soybean output levels.

Prasad, Rajendra et.al. (2014). In 2011, researchers surveyed 10 villages in the Panna district of the Bundelkhand area to gauge farmers' views on the dangers posed by climate change and their plans to adapt to make their crops more resilient. It is evident from the findings that farmers have a good grasp of how different climate scenarios would affect agriculture and associated sectors. The agricultural production system is in jeopardy due to the weather pattern deviation, monsoon rain, wind, and dust storms, as well as the rise in uncommon weather extremes. Changes in crop phenology posed a definite threat to biodiversity, as evidenced by variations in blooming time and intensity, fruit-bearing patterns, grain shape, size, quality, and overall appearance. It was also believed that the production of cattle was in jeopardy as a result of climate change. To reduce the likelihood of adverse agricultural conditions, increase animal output, and better handle severe weather, the farmers in the research region have used a number of adaptation strategies. One of the key adaptation techniques for creating resilience in agriculture was to change the timing of crop planting and the order of cropping. Another strategy was to grow trees on field borders and in the backyard as part of agroforestry.

Dupare, B. et.al. (2021). In light of the anticipated effects of climate change, this research looked at how soybean farmers see the phenomenon and how they plan to adapt to it. In Madhya Pradesh's Diwas, Indore, and Dhar districts which are part of the Malwa plateau and Nimar valley 280 rural farmers were chosen using a multi-stage selection process. The research area's popularity of monocropping soybeans and the gradual loss of crop diversity were both highlighted by the findings. The area's cropping intensity was shown to be significantly enhanced with the introduction of soybean. The majority of farmers reported experiencing abiotic weather-related pressures such as a delayed monsoon, unpredictable rainfall, fewer wet days, higher temperatures, more sunny hours, and lower humidity. A decline in yearly rainfall was seen by the majority of farmers. Additionally, they saw that biotic stressor, such as weeds, insects, and illnesses, had grown considerably over time.

Prasad, Ravindra et.al. (2017). Climate change is having a devastating effect on the agricultural industry, which is already struggling to meet the increased demand for food caused by a growing population. Climate change is putting increasing pressure on the world's agricultural environment via phenomena like higher average temperatures, changed patterns of precipitation, more intense and frequent weather events, and so on. Agric produces a large amount of the greenhouse gases (GHGs) that contribute to global warming. Changes in land use account for an extra 7–14% of these emissions, while agricultural activities account for around 17%. With 58% of the population working in agriculture, it's no wonder that it accounts for the bulk of the Indian subcontinent's GDP. One strategy the Indian government is using to combat climate change is to abandon conventional agricultural practices in favor of policies that are climate-smart, diverse, adaptation-and mitigation-focused. In order to lessen the negative effects of climate change on the agricultural sector, this chapter covers adaptation and mitigation measures. Also covered were the many initiatives now underway by the Indian government to promote long-term productivity.

RESEARCH METHODOLOGY

In Madhya Pradesh, we conducted research to determine the effects of climate change on potato yields, as well as to determine the best time to plant and which cultivar to use to mitigate these effects. Utilizing time course data on potato growth and development gathered from field experiments carried out at MP from

2021 to 2023, this model has been verified for Indian potato cultivars belonging to the late (Kufri Badshah), medium (Kufri Jyoti and Kufri Bahar), and early (Kufri Pukhraj) maturity groups. The Indian Meteorological Department (IMD) used the district normals for 38 districts in Madhya Pradesh from 1994 to 2023 to create a baseline scenario for the year 2000 (Table 1). For the development of 2020 and 2055 scenarios, the baseline data was enhanced with the addition of the Atmosphere-Ocean General Circulation Models (AOGCMs) from the Fourth Assessment Report (AR4). This allowed for the incorporation of the predicted increases in surface air temperature for sub-regions of Asia under the SRES A1FI route. (IPCC, 2007).

The research relies on secondary data sourced from the India Meteorological Department (IMD), this includes, according to WMO standards, the number of wet days, highest and lowest temperatures, and total rainfall for a 60-year span (from 1951 to 2010). The District Agriculture Statistics Handbook is the source for the data on the growth rate of food production. The data on the location of groundwater comes from the Groundwater Commission. The Government of Rajasthan's official website provides this data, which includes information on poverty, per capita income, and the source of income. We look at the climatic variability throughout space and time. The trend of climate factors over the last 60 years has been determined using moving averages. In a similar vein, the changes in climatic zones proposed by Thornthwaite are also calculated using the same program. When appropriate, we have also made use of statistical methods like regression and correlation. This kind of analysis has been conducted using SPSS software.

DATA ANALYSIS

According to the findings of the WOFOST model's simulations, under the baseline climatic scenario (2000), potato production throughout the state varied greatly. Even within states, there was a wide range in potato yields.

Table 1: At the ten most productive potato-growing districts in Madhya Pradesh, WOFOST projected future climatic conditions and baseline (2000) production levels for several potato varieties.

S. No.	Station	Area (ha)	*Kufri Badshah*				*Kufri Jyoti*		*Kufri*	*Pukhraj*	
		Under potato (2022-23) *	Base line yield	Change (%)		Base line yield	Change (%)		Base line yield	Change (%)	
			($t\ ha^{-1}$)	2020	2055	($t\ ha^{-1}$)	2020	2055	($t\ ha^{-1}$)	2020	2055
1	Chhindwara	4897	48.3	-5.7	-9.8	44.9	-6.9	-11.6	48.1	-6.9	-13.3
2	Dewa's	8560	38.0	-5.5	-11.0	34.8	-5.6	-13.2	37.0	-6.9	-16.3
3	Indore	20124	39.4	-6.5	-11.2	35.5	-6.7	-13.3	37.2	-7.1	-13.7
4	Morena	2076	49.7	-6.5	-12.0	44.5	-7.5	-14.0	46.7	-9.0	-16.9
5	Panna	1683	44.9	-5.7	-11.1	41.4	-6.8	-12.7	42.8	-7.4	-13.8
6	Rewa	2463	48.2	-5.0	-9.9	44.9	-6.7	-12.1	47.2	-6.7	-12.8
7	Sagar	2543	34.5	-7.7	-14.0	30.0	-7.7	-13.2	30.0	-6.5	-13.0
8	Satna	3536	44.0	-5.7	-10.4	40.2	-6.6	-11.9	42.1	-7.8	-14.1
9	Shajapur	6066	45.3	-6.0	-9.9	41.5	-6.6	-10.9	44.3	-6.7	-11.6
10	Ujjain	7211	44.8	-6.1	-10.4	40.9	-6.9	-11.7	43.7	-7.1	-12.7
Mean of top 10 districts			43.7	-6.0	-10.9	39.9	-6.8	-12.5	41.9	-7.2	-13.8
Mean of 38 districts			44.2	-5.8	-10.4	40.6	-6.6	-12.3	42.8	-7.1	-13.9

Overall, the yields of Kufri Jyoti and Kufri Pukhraj ranged from 23.6 $t\ ha^{-1}$ (Dhar) to 48.6 $t\ ha^{-1}$ (Gwalior and Shivpuri), whereas Kufri Badshah's production ranged from 26.8 $t\ ha^{-1}$ (Dhar) to 52.2 $t\ ha^{-1}$ (Shivpuri). Out of 38 districts in Kufri Badshah, 42.8 t ha-1 was the average production, whereas 40.6 t ha-1 was in Kufri Jyoti. Similar results were obtained from the top ten districts in terms of potato production (Table 1).

Table 2: A connection between the growth processes and the rise of CO2

	2020	2055
Change in light-use efficiency of single leaf	+10% x (415-367)/355 = +1.4%	+10% x (590-367)/355 = + 6.28%
Change in maximum leaf CO_2 assimilation rate	+55% x (415-367)/355 = +7.4%	+55% x (590-367)/355 = +34.5%

The projected changes in atmospheric CO_2 levels have a direct influence on plant photosynthetic efficiency. In the year 2020, the concentration of CO_2 is estimated to have increased to 415 ppm. This rise leads to a 1.4% increase in the light-use efficiency (LUE) of a single leaf a measure of how effectively plants convert light into chemical energy during photosynthesis. Additionally, the maximum CO_2 assimilation rate, which reflects the upper limit of photosynthetic capacity, is estimated to have increased by 7.4%.

By 2055, atmospheric CO_2 is expected to rise further to 590 ppm, resulting in a 6.28% increase in LUE and a more substantial 34.5% increase in the maximum CO_2 assimilation rate. These changes suggest that elevated CO_2 concentrations could enhance photosynthetic capacity and potentially boost crop productivity, assuming other growth factors (like water and nutrients) are not limiting. However, while this CO_2 fertilization effect may provide some compensation against yield loss due to temperature and rainfall changes, it is not sufficient to fully offset the negative impacts of climate change on overall crop productivity, especially in water-scarce regions like Madhya Pradesh and Rajasthan.

Table 3: Impact of future climates on the productivity of potato cultivars in the baseline year (results extrapolated for the whole geographical region of MP)

	Kufri Badshah	Kufri Jyoti	Kufri Pukhraj
Baseline yield (t ha^{-1})	43.6	40.0	42.2
Overall reduction in yield (%)			
2020	6.4	7.3	7.6
2055	10.9	12.8	14.3
Yield reduction classes (%) in 2020	% geographical area of MP		
5-6%	56.3	6.9	0.9
7-8%	43.7	93.1	96.7
9-10%	-	-	2.4
Yield reduction (%) classes in 2055			
7-9%	34.8	5.0	-
10-12%	63.3	83.7	69.2
13-15%	1.9	11.3	24.7
16-18%	-	-	6.1

In Madhya Pradesh, three prominent potato cultivars Kufri Badshah, Kufri Jyoti, and Kufri Pukhraj will be analyzed to determine the predicted effect of climate change on their yields between 2020 and 2055. The average yield under baseline climatic circumstances was 43.6 t/ha for Kufri Badshah, 42.2 t/ha for Kufri Pukhraj, and 40.0 t/ha for Kufri Jyoti.

By 2020, a moderate decline in yield is projected: 6.4% for Kufri Badshah, 7.3% for Kufri Jyoti, and 7.6% for Kufri Pukhraj. Notably, a large portion of the state's geographical area falls under the 7–8% yield reduction class, particularly affecting Kufri Jyoti (93.1%) and Kufri Pukhraj (96.7%). In contrast, 56.3% of the area growing Kufri Badshah will experience only a 5–6% yield reduction, indicating that Kufri Badshah may initially show better climate resilience by 2020.

By 2055, the scenario worsens, with significant yield reductions: 10.9% for Kufri Badshah, 12.8% for Kufri Jyoti, and 14.3% for Kufri Pukhraj. The most affected areas fall under the 10–12% yield reduction class, covering 63.3% of Kufri Badshah's area, 83.7% for Kufri Jyoti, and 69.2% for Kufri Pukhraj. Alarmingly, Kufri Pukhraj also has 6.1% of its growing area falling under the 16–18% yield reduction class, indicating severe sensitivity to future climate conditions.

Trend Productivity in Agriculture

While most agro-climatic zones saw a plateau in kharif crop yields after the mid-1970s, Rajasthan's agricultural acreage, output, and productivity all rose steadily during the past four decades (Chand, Garg, and Pandey 2009). Contrarily, the area under cultivation for rabi crops is always on the rise. A nationwide examination of agricultural output broken down by district. This groundbreaking study not only analyzed agricultural growth at the disaggregated level of crops but also produced productivity estimates.

This examination spanned the years 2020–2023. Varying parts of the state have seen a fall in kharif pulse productivity, with IIB (2008.53 to 853.97), IVA (1056.16 to 327.20), and IV (2121.13 to 16.10) experiencing the worst drops. Additionally, maize production has been declining across the board with the exception of regions IV, B, and V, which, thanks to their favorable physical circumstances, have seen a respectable uptick. Productivity increases in IB, IIA, IIB, and IIIA are unique to pearl millet. The production of pearl millet and sorghum has grown in IIB and IIIA, as shown in Table 4.

Table 4: Crop Efficiency of Major Kharif Crops

	Sorghum		Pearl Millet		Maize		Kharif Pulses	
	1951-60	2001-10	1951-60	2001-10	1951-60	2001-10	1951-60	2001-10
IA	103.76	94.68	3220.17	2566.34	5.94	0.16	218.53	132.99
IB	599.33	0.83	965.46	1175.03	47.89	0.45	65.73	23.45
IC	65.63	13.52	1664.33	1215.42	0.24	0.00	184.64	46.78
IIA	488.23	179.38	3063.18	5016.59	15.93	1.15	231.47	238.40
IIB	680.71	689.81	2467.51	3106.73	277.36	212.27	2008.53	853.97
IIIA	1460.78	1509.76	2337.88	5019.76	863.06	383.10	517.48	216.19
IIIB	1726.67	1251.15	5073.12	12586.15	229.95	145.20	338.40	333.19
IVA	620.12	740.73	516.63	185.71	4889.45	6148.17	1056.16	327.20
IVB	78.28	33.53	41.50	4.96	3283.45	4529.46	2124.13	16.10
V	9125.69	853.26	122.97	70.74	1032.52	1893.89	493.88	157.97

The production of all main rabi crops has declined somewhat in zones IA and IV B. Since the early 1990s, Indian agriculture has seen a dramatic transformation. Zones IIA, IIIA, and IVA show a decline in wheat, gram, and mustard production (Table 5).

Table 5: Crop Efficiency of Major Rabi Crops

Zone	Crop	Trend
IA	All Rabi Crops	Decline
IVB	All Rabi Crops	Decline
IIA	Wheat, Gram, Mustard	Decline

IIIA	Wheat, Gram, Mustard	Decline
IVA	Wheat, Gram, Mustard	Decline

This table summarizes the zonal trends for rabi crop efficiency, highlighting widespread declines in productivity, particularly in zones IIA, IIIA, and IVA for wheat, gram, and mustard, and a general decline across all rabi crops in zones IA and IVB.

The Guiding Principle of MP SAPCC

In order to build a climate-resilient state, the Government of Madhya Pradesh (GoMP) created the State Action Plan on Climate Change (SAPCC) to handle regional issues. By implementing policy-level interventions that promote low-carbon growth, the state's developmental planning process will be bolstered by the methods and suggestions of the SAPCC. Given the importance of vulnerability and adaptation (V&A) in Madhya Pradesh, the SAPCC is dedicated to developing effective adaptation strategies via vulnerability assessments. These strategies will then be integrated and mainstreamed into the relevant policies and programs. Here are some guidelines to consider while developing the redesigned SAPCC: - The MoEFCC Structure

1. Compatibility with NDC, SDGs, and SBSAP.
2. The Third Concept: Eco-Friendly Design.
3. The primary focus is on adaptation.
4. Climate Actions Focused on Ecosystems.
5. Taking Advantage of Opportunities for Mitigation.
6. Making Climate Change a Priority.
7. Issues of gender and climate change are at the forefront.
8. Climate Actions would be prompted by Climate Knowledge.
9. A Consultative and Participative Approach.
10. Research, instruction, public awareness, and education with a focus on strategy.

Adaptation to Changing Climate of Rajasthan

Table 6 shows that farmers have chosen a few ways, but that financial gains, rather than merely knowledge, are their driving factor. Change of variety (86%), changing of sowing dates (87%), and increased irrigation (83%), out of 15 adaptation techniques, were the most often used. According to the literature, these methods are recommended by most researchers as a means to minimize losses and avoid heat stress.

Table 6: Adaptation strategies opted by respondents and reasons of adoption (values in %).

Adaptation strategy	Adopted	Reasons for adoption		
		Knowledge	Monetary benefit	Both
Shifting of sowing dates	87	28	46	26
Increase irrigation	83	46	43	11
Mixed farming	47	35	53	12
Contract farming	12	3	77	20
Shift to non-agriculture	51	8	87	5
Conservation agriculture	24	37	59	4
Opted dairy/poultry	31	34	60	7
Change in crop area	38	36	55	10
Variety change	86	37	46	17
Soil testing	49	30	59	11
Crop insurance	37	23	71	5
Water harvesting	10	74	19	6
Agro-forestry	37	36	59	5
New technology	29	25	57	17
Crop change	56	43	45	12

CONCLUSION

According to the results, new potato varieties with a higher bulking rate and tolerance to high temperatures are required. In addition to improving yield, these stress-tolerant cultivars may help in dealing with climatic unpredictability. Rainfall is the primary means of irrigation in the majority of Indian states, and this is particularly true in Rajasthan. Any shift in rainfall patterns jeopardizes agriculture, the state's economy, and food security. Modifications to both the overall amount and timing of precipitation harm farming. Due to increasing temperatures during the kharif season, the production of pearl millet—a significant crop in Rajasthan—is anticipated to decline.

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