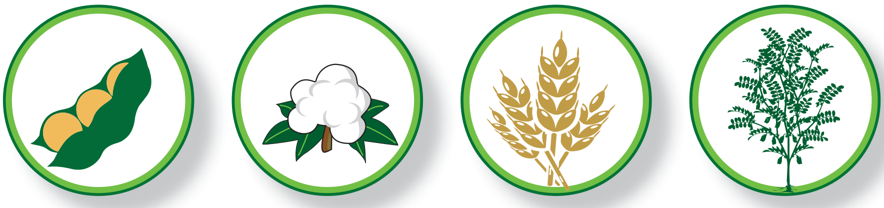
INSTITUTE FOR Sustainable Communities

CLIMATE CHANGE IMPACTS on Maharashtra Agriculture



CLIMATE CHANGE IMPACTS
on Maharashtra Agriculture

Research Direction and Editor: Romit Sen

Authors: Chaiti Bhagawat and Divya Nazareth

Inputs: Sushama Darne and Ravikant Kumar

Design: Ravinder S Khati

Photographs: Romit Sen, Sushama Darne, Ravikant Kumar and Sagar Tayade

The Team acknowledges the support of the farmers and of Mr. Mahesh Sadatpure, Mr. Amit Mhetre, Dr. Milind Sable and Mr. Gajendra Chawde for their inputs.

Citation: Sen Romit, Bhagawat Chaiti, Nazareth Divya, 2021, Climate Change Impacts On Maharashtra Agriculture, Institute for Sustainable Communities

Institute for Sustainable Communities

The Institute for Sustainable Communities (ISC) is a global non-profit organization with a 30-year track record of supporting industry, cities, and communities to plan and implement environmental, economic, and social improvements. Since its founding in 1991, ISC has implemented 118 projects in 30 countries.

ISCs core organizational approach is to unleash the power of people to transform their communities. This approach ensures that solutions emerge from within the community, rather than being imposed from the outside. ISC develops the capacity of local organizations, to increase their capabilities, to leverage specific technical and contextualized knowledge, and to embed solutions locally to deliver lasting change.

With current projects in India, Bangladesh, China and the US, ISC has a diverse and growing portfolio of projects in areas such as water resources, sustainable agriculture, energy efficiency, renewable energy, and environment, health, and safety (EHS) practices for the manufacturing sector, climate adaptation and community resilience.

Contents

Foreword

Agriculture is amongst the most important sectors in Maharashtra, contributing significantly to its economy. With a net sown area of 168.15 lakh hectares, engaging close to 50% of the state's population, the importance of agriculture cannot be undermined. Aided by several advancements, proactive policy measures, improved access to inputs, better extension and increase in area under cultivation, the sector has benefited over the past several years. However, despite all progress the inherent challenges faced by farming communities have remained due to various externalities and factors.

Current farming practices have continued interventions based on historical weather patterns, prevailing for many decades in the past. Climate Change has distorted these trends, leading to increased extreme events, significantly affecting agriculture yields, livelihoods and soil health. Various studies have mapped out impacts of fluctuations in temperature and rainfall, on growth and development of crops, indicating warning signs for agriculture in Maharashtra.

Further, manifestation of climate change impacts, at a local level differ significantly outlining a gap, warranting more granular assessments and resilience measures. At the Institute for Sustainable Communities (ISC), we have attempted to address this gap, aiming to drive a more actionable understanding amongst key decision makers, researchers and farming communities. Our analysis across major regions in the state, namely, Vidarbha, Marathwada and Khandesh for four major crops grown in these regions – Soybean, Cotton, Wheat and Gram, surfaces key findings based on an innovative, robust three-pronged approach.

The analysis presented in this report, maps climate modelling and projections (both historical and futuristic), with crop phenology (optimal conditions across each of the growing stages for a crop) coupled with community based participatory assessments (on-ground farmer validation), at a much granular 'weekly' scale to weave a comprehensive understanding on the vulnerability of farmers.

Fluctuations in temperature and rainfall patterns going forward are likely to be detrimental for growth and development of each of the four crops (under the scope of our study). In case of the Kharif crops - Soybean and Cotton, excess rainfall especially during the pod development and maturity, boll formation and boll bursting stage is expected to significantly impact production and quality of the produce. For the Rabi crops – Wheat and Gram, high temperatures during the grain formation and filling stage similarly are likely to affect the quality of the produce. In response, this report also outlines, adaptive measures undertaken by farming communities to adapt to these trends, paving the way for localized scalable solutions for climate resilient agriculture in the state.

Lastly, we encourage additional research to further advance understanding of climate change linkages, predicting exact impact on yield and production of other crops. We do hope the methodology, analysis, findings and recommendations outlined in this report, would help develop a better perspective on impacts of climate change on agriculture in the state.

Vivek P Adhia
Country Director – India
Institute for Sustainable Communities

1
Introduction

Crops are sensitive to the environment around them. At a macro level plants need air, water and sunlight to grow, but factors that affect plant growth are far more complex. Abiotic (non-living) factors impacting healthy plant growth are sunlight, cloud cover, wind, rainfall, soil moisture, soil nutrients, dust, atmospheric gas concentrations, humidity and temperature and biotic (living) factors are soil microbial communities, pollinators, agents of seed dispersal, insects, fungi and animals, including humans. Unable to change their location, plants are at the mercy of the climate and ecosystem they are in. Humans can control several of the abiotic and biotic factors to favour high yields for crop plants in our agricultural systems, but a majority – such as temperature and rainfall – are beyond human control.

Current farming practices are set to the climatic patterns that have prevailed for decades in the past, but we know now that global climate is changing. Through the effects of human activities, increased greenhouse gases like carbon dioxide, methane, nitrous oxide and fluorinated gases are causing a warming effect coined as climate change. Rising temperatures, changes in precipitation patterns, an increase in frequency and intensity of extreme weather events like droughts, heat waves, floods and hurricanes, rising sea levels and complete loss of arctic ice are some of the main predicted impacts of climate change, but smaller scale and complex effects are expected to impact our lives in many ways.

The negative effect of changing rainfall and temperature patterns on agriculture has already been observed and is predicted to grow worse. Agriculture faces increasing population pressure, declining land and water availability and declining soil fertility. Climate change is a new stressor for our cropping systems. As crops suffer, farmers and workers who depend on these crops, not only for sustenance but also for livelihood are increasingly at risk. Developing countries like India with large populations dependent on agriculture for their livelihoods are especially vulnerable to climate change, and must take steps to identify coming risks and possible mitigation strategies.

1.1 Agriculture in Maharashtra

Maharashtra is India's second largest state by population (11.24 crore / 111 million people), and third largest by area (308 lakh sq. km). It lies along the west coast of peninsular India and has the highest nominal Gross Domestic Product (GDP) of all Indian states. Roughly 55% of Maharashtra's population is rural, and the literacy rate is 82.3%, according to the 2011 census.

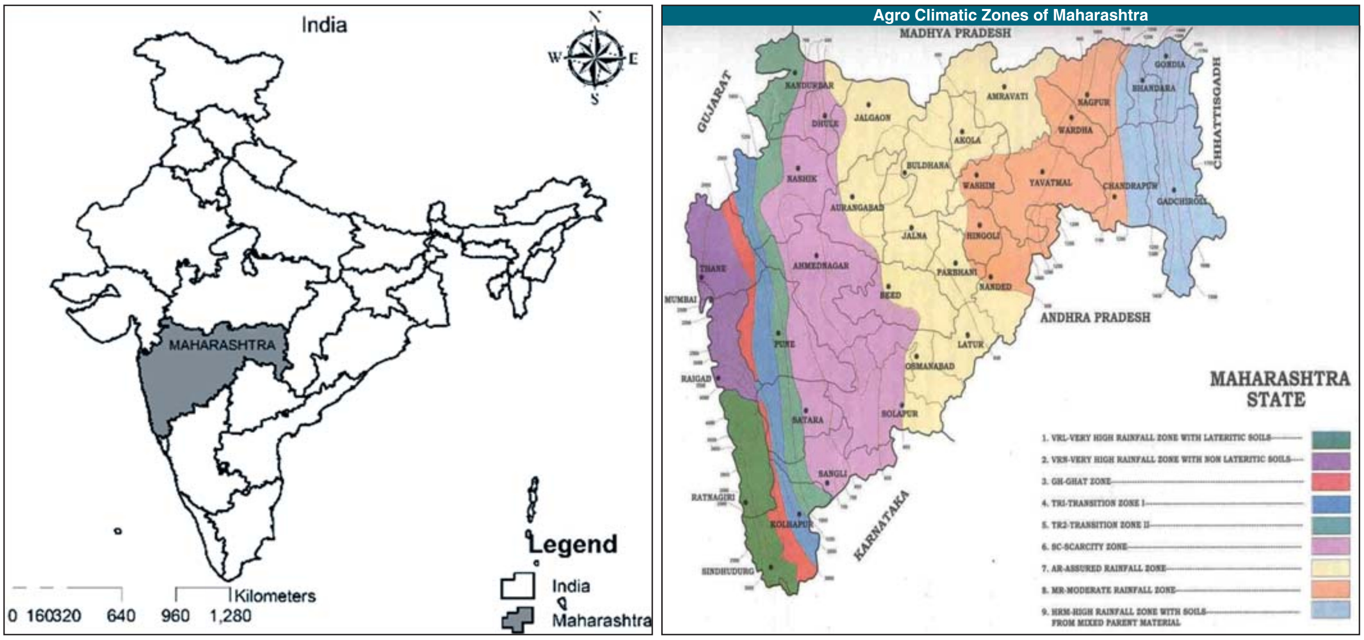


Figure 1: Location of Maharashtra

Maharashtra's climate is generally characterized by hot summers, monsoon and then mild winters. The coastal region of Maharashtra falls into the Hot Humid-Perhumid Eco-Region, with hot and humid summers, warm winters and a mean annual rainfall in excess of 2000 mm. The western and central parts of Maharashtra fall in the Hot Semi-Arid Eco-Region and have hot and humid summers, mild and dry winters and mean annual rainfall of 600-1000 mm. Most of eastern Maharashtra lies in the Hot Sub-Humid (Dry) Eco-Region and has hot summers, mild winters and mean annual rainfall of 1000-1500 mm, with an increasing trend towards the east. The regions focused in this report fall in the Hot Semi-Arid and Hot Sub-Humid regions.

Agriculture in Maharashtra is primarily rainfed, with only 18.2% of crop area irrigated. The net sown area for agriculture in 2018-2019 was 168.15 lakh hectares, or about 55% of the total geographic area. Over 50% of the state's population is dependent on agriculture for their livelihoods, but in the last decade only 11.7% of the Gross State Value Added came from agriculture and allied activities. The 2015-16 agriculture census found the average size of an operational holding to be 1.34 ha, classified as small. Operational land holding size patterns are given in Table below.

Table 1: Land holding in Maharashtra

Holding Size:	Number of Holdings	% of Holdings	% of Area
Marginal (up to 1.0 ha)	78 lakh	51%	16%
Small (1.0-2.0 ha)	43 lakh	28%	28%
Semi-Medium (2.0-4.0 ha)	23 lakh	15%	29%
Medium (4.0-10.0 ha)	7 lakh	5%	21%
Large (10.0 ha and up)	0.69 lakh	<1%	6%

Source: Economic Survey of Maharashtra 2020-21

Cereals, pulses, oilseeds, cotton and sugarcane are the broad categories of crops grown. The main cereal crops grown are jowar, rice, maize, wheat and bajra. The main pulses grown are gram, tur, moong and udid. Soybean dominates the oilseeds grown, with groundnut next. The total areas cultivated under these crops in 2019-2020 is indicated in Table 2.

Table 2: Area under major crops							
Cereals	**Area('000 ha)**	**Pulses**	**Area('000 ha)**	**Oilseeds**	**Area('000 ha)**	**Cash Crop**	**Area('000 ha)**
Jowar	2,257	Gram	2,043	Soybean	4,124	Cotton	4,491
Rice	1,547	Tur	1,319	Groundnut	221	Sugarcane	822
Maize	1,070	Moong	387	Sesamum	22		
Wheat	1,057	Udid	341	Sunflower	22		
Bajra	673			Safflower	22		
Source: Economic Survey of Maharashtra 2020-21							

Around 40% of Maharashtra is drought prone. The present study looks at Khandesh, Marathwada and Vidarbha, three regions that fall in the drought prone area. Khandesh, Marathwada and some parts of Vidarbha are a part of the Hot Semi-Arid Eco-Region, and other parts of Vidarbha are in the Hot Sub-Humid Eco-Region. Drought events lead to crop failure, reduction in employment of unskilled labour and increased debt for farmers. A drought in 2012 resulted in an estimated 21% yield reduction in cereals, 5% in pulses and 18% decline in total food grains production. Sugarcane, citrus fruits and vegetables also suffered significant yield losses. Central Maharashtra and Marathwada have the highest incidences of drought, making them particularly vulnerable to climate change.

1.2 Climate Change and Agriculture

The effects of climate change on agriculture can be grouped into effects caused by rising temperature, changing rainfall patterns, rising atmospheric carbon dioxide and rising atmospheric ozone. A summary of effects is provided in Table 3.

Table 3: Effects of Climate Change on Crops	
Temperature Rise	• Shortened crop duration, leading to less time for grains to develop • Harm to reproductive system—flowering and fruiting • Direct damage to plant cells • Increased transpiration and water loss • Increased pests and diseases • Damage to plant-microbe relationships • Changes in soil nutrient cycles
Unpredictable Rainfall	• Reduced yield from drought stress • Loss to rainfed farmers due to rain schedule changes • Root damage from flooding • Loss of soil nutrients from flooding
Atmospheric Carbon Dioxide Rise	• Increased photosynthesis • Decreased O_2 related photosynthesis loss • Possibly higher water use efficiency • Changes in Nitrogen use of plants • Changes in plant C:N ratios leading to altered pest and disease patterns
Atmospheric Ozone Rise	• Oxidative damage to photosynthetic machinery • Possible reduction of radiation available to plants

1.2.1 Temperature

Temperature rise affects crop physiology, crop water balance, pest population, and soil biology and chemistry. A rise in temperature leads to faster crop development, and a shorter growing period, which means less robust growth. Higher daytime temperatures decrease photosynthesis rates in crops and higher night time temperatures increase respiration requirements, leading to overall lower carbon fixation. Extremely high temperatures cause direct damage to plant cells. Heat stress during the reproductive phase may lead to sterility, reduced fruiting, impacted grain filling, and sometimes even total crop failure. However, in areas where photosynthesis currently occurs at below optimal temperature and frosts prevail, an increase in crop yield may be seen. Warming of air leads to an increased vapor pressure deficit between leaf and air, causing more transpiration and more chances of stomatal closure during the day, which stops photosynthesis in most crop plants.

Rising temperature can favour increased survival of pests and diseases and their spread. Pests will be able to survive warmer winters in higher numbers, and pests, vectors of plant diseases, and weeds and weed hosts for pests will all be able to radiate towards the poles. Increasing atmospheric temperature is closely linked to increasing soil temperature, which causes changes in the soil community. Increased soil temperatures affect plant-microbe interactions and lead to reduced or impaired nodule formation, which is harmful to leguminous crops. Higher soil temperatures lead to increased volatilization of compounds, reducing soil fertility through dissipation of assimilated soil carbon and trace minerals and gases. Rising soil temperatures also lead to increased mobility of metals in soil and possibly increased bio-accumulation in crop tissues, which is harmful to human health and soil micro organisms.

1.2.2 Precipitation

Increased variability in precipitation caused by climate change leads to droughts and extreme weather events like flooding and hailstorms, which have drastic effects on crops. Plants respond to drought by closing stomata and slowing carbon uptake, leading to lowered yield. Increased agricultural droughts and changes in the timing of onset of the rainy season will devastate rain-fed farmers. Drought during the reproductive phase is particularly harmful to yield. Heavy rainfall in a short period leads to water logging, which is damaging to crops as plant roots are unable to respire. Often, soil nutrients are leached by the floodwater.

High temperatures after flooding promote humidity, leading to an increase in pests and disease. The persistence of a chemical pesticide on a plant is dependent on temperature and precipitation patterns, and changes may lead to early degradation of pesticide molecules and reduced impact on pests and diseases.

1.2.3 Green House Gas Emissions

Rising atmospheric carbon dioxide may have a positive or negative effect on crop plants. Increased carbon dioxide availability leads to greater accumulation of carbon, and potentially better yields. It may lead to a higher water use efficiency, as more CO_2 will be fixed per water molecule. On the flip side, it may lead to a change in the nutritional composition of crop plants, with greater concentration of sugars and lower assimilation of nitrates. Pests will need to consume more such leaves to gain the same amount of nitrogen, and sugar dependent organisms like rusts will thrive on such leaves.

Rising atmospheric ozone results from air pollutants like nitrous oxides, carbon monoxide, and methane reacting with hydroxyl ions in the lower atmosphere. Ozone causes oxidative damage to the photosynthetic machinery in all major crop plants. Aerosols may reduce the radiation available to plants. The impacts of ozone are worst in areas downwind of urban or industrial areas, but ozone can travel long distances with the wind.

Developing countries with large farming populations and unskilled farm workers are particularly vulnerable to the combined effects of climate change on crop production and agricultural labour. As days get hotter, working hours will reduce, along with income and yields, leading to a future crisis. Developing countries are more vulnerable to climate change, as many of them lie close to the equator, where temperatures will eventually become very high, and they lack technological resources to combat the increased risks to crops. They are more dependent on rainfall for agriculture but produce most of the world's food.

1.3 Crop Information

The present study analyses the impact of four major crops grown across the Kharif (Monsoon) Season viz, Soybean and Cotton and Rabi (Winter) season namely Wheat and Gram. Section below outlines a brief description of all the crops.

Soybean is a legume grown in the Kharif season primarily as an oilseed, and also as a source of processed protein. It is the fastest-growing oilseed globally and has helped to make up the deficit between India's oil production and oil consumption. Soybean is a short-duration crop and is harvested right before rabi sowing dates. Grown commercially in India since the 1970s, it became popular due to the significant profit farmers were able to make from it. Due to the inadequate spread and adoption of soybean technology packages, yields in India are low and have plateaued. In 2020, 16.071 lakh ha of soybean were planted in Vidarbha, 16.055 lakh ha in Marathwada, and 4.252 lakh ha in Khandesh.

Cotton is a long period fiber crop, sown in the Kharif season and harvested from November to March of the following year. The cotton crop produces a boll as fruit, containing fluffy cotton lint surrounding the cotton seed. Cotton seeds are used as a part of the hydrogenated oil industry, and the lint forms 78% of India's total textile consumption. Maharashtra has the largest cropped area in India under cotton, and second largest production of cotton in India.

Since the introduction of Bt Cotton seeds in Maharashtra in 2002-2003, they have become the preferred type of cotton to be sown, and around 96% of farmers cultivate it. The remaining farmers grow desi cotton. High yielding Bt cotton varieties require irrigation and ample inputs for best performance, but most farmers cultivating it in Maharashtra do not have access to irrigation, which may be a factor in the low yields seen across the state. It is a water intensive crop, needing 100-150 cms of water annually, and suffers from many pest attacks, which require extensive pesticide use. Khandesh, Marathwada and Vidarbha are the main producers of cotton in Maharashtra, and usually farmers grow short period kharif and rabi crops alongside cotton.

Wheat is a global short period cereal crop, and is the most widely grown staple crop. It is grown in India in the Rabi season, and is planted in November and harvested in March/April. Traditionally, farmers in Khandesh, Marathwada and Vidarbha sow wheat and other Rabi crops when coconut oil solidifies, using this as a simple marker of germination temperature. Wheat is consumed as a part of daily staples in most of North India, and the northern states are the primary producers of wheat in India. In Maharashtra, wheat is grown mostly by farmers who have access to irrigation, as it needs to be irrigated 5-6 times through its crop cycle. Winter wheat in Maharashtra is comparatively hardy, and has few pests and weeds. Since it is a food crop, parts of the farmer's harvest can be stored at home for consumption. As a winter crop, wheat is particularly sensitive to temperature, and requires cold weather for optimal growth and yield. Rising temperatures in the future are thought to have a significant impact on wheat.

Gram, or chickpea, is a legume crop grown and its beans are consumed in Maharashtra in a wide variety of ways. It is grown in the Rabi season, from November to March/April and also needs cold temperatures for adequate growth. Earlier, when soil moisture holding capacities were higher in Khandesh, Marathwada and Vidarbha, gram could be grown on the residual moisture in the soil after the monsoons. Now only those farmers with access to some irrigation can grow gram, as it needs to be irrigated 1-2 times.

Gram is a nitrogen-fixing plant and fixes up to 70% of its own nitrogen requirements, and is the second most widely cultivated legume after soybean. Like wheat, it is a low weed and low pest crop, and its yields are at risk due to rising temperatures. India is highest global producer of gram and Maharashtra produces the second highest amount, after Madhya Pradesh.

1.4 Study Scope and Purpose

The report examines the effect of climate change on four major crops and farmer livelihoods in the State of Maharashtra. Farmers in Central and Eastern Maharashtra are already experiencing setbacks due to climate change. Based on an analysis of climate data (combining historical climate data analysis and future predictions), farmer interviews and secondary literature analyses, the report brings out the current problems and future risks faced by farmers in the state. A stage-wise analysis of four major crops, namely soybean, cotton, wheat and gram has been used to not only look at the climate risks, the impact on farmers, their current response but also to inform future interventions to reduce the vulnerabilities of farmers.

The findings of the study aim to inform adaptation strategies to reduce farmer vulnerability to climate change across the different regions of Maharashtra. Understanding the present scenario and knowing specific risks the future holds will help determine which mitigation strategies farmers can employ. Beyond the local scope, the inferences can be easily applied to other semi-arid regions growing similar crops, and the framework of analysis used in the study can be applied to any location to inform local adaptation practices.

2
Research Approach

The following sections present an overview of the objectives, approach and methodology deployed to explore the vulnerability of four crops namely soybean, cotton, wheat and gram to climate and non-climate risks in State of Maharashtra.

2.1 Objectives

The objective of this study was to assess how vulnerable soybean, cotton, wheat and gram crops were to extreme changes in local weather patterns across each of its major growth stages. To characterize this vulnerability, the study specifically looks at:

CLIMATE ANALYSIS

Analyzed trends in seasonal (kharif and rabi) and monthly rainfall and temperature (minimum and maximum) over a 60-year period (1989-2018 & 2021-2050).

CROP PHENOLOGY

Examined the effects of the climate risks on the growth and development of each stage of the four crops

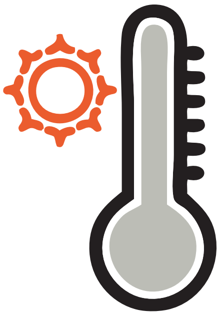
COMMUNITY ADAPTATION

Investigated how farmers were coping and adapting to the impacts of climate change and non-climate stressors

2.2 Framework

The vulnerability framework that stipulates that vulnerability is determined by exposure, sensitivity and adaptive capacity guided the analysis for this study. Exposure can be understood as direct danger stemming from variations in temperature and rainfall. Sensitivity is considered to be a first order impact of climate hazards on human-environment systems. The adaptive capacity of a system is reflected in its ability to respond, exploit opportunities and recover from external stresses. This ability to cope better could stem from access, mobilization and utilization of assets and entitlements.

Essentially, according to the vulnerability framework, a certain degree of vulnerability is created by climate change (exposure) , however this is either exacerbated or mitigated based on the resources available with communities (sensitivity and adaptive capacity) to cope, adapt or mitigate impacts from these hazards.

VULNERABILITY FRAMEWORK		
EXPOSURE	**SENSITIVITY**	**ADAPTIVE CAPACITY**
		
Direct danger from climate events. Examples include drought and heat/cold waves.	First order impact of climate hazards on human-environment systems. Weaknesses in a system can enhance sensitivity while its strengths can enhance adaptive capacity. For example, the presence of irrigation facilities makes a farmer less sensitive to dry spells.	Ability to respond and re-cover from external stresses. This ability to cope better stems from access to and ownership of re-sources/capital. Examples include access to weather advisory services, knowledge of climate smart agriculture and possession of crop insurance.

2.3 Approach and Methodology

The findings from climate analysis, a literature review of impacts of climate change on crop phenology and farmers interviews on current adaptation measures were correlated to weave a comprehensive narrative on the vulnerability of agriculture sector in Maharashtra.

For the climate analysis component, rainfall and temperature were analyzed over two periods – historical period comprising of thirty years from 1989 to 2018 and future trends were projected for the period between 2021 to 2050. Data obtained from the Indian Meteorological Department (IMD) was used to conduct the analysis for the historical period while the projections were undertaken using datasets from NASA Earth Exchange (NEX). To model rainfall and temperature for the coming decades, the Representative Concentration Pathway (RCP) 8.5 was adopted. This RCP assumes that Green House Gas (GHG) emissions will continue to rise throughout the 21st century and is the worst-case scenario among a suite of RCPs.

To understand the major growth and development stages of soybean, cotton, wheat and gram crops, academic scholarship on the subject was extensively reviewed. First the different stages of the crops were identified. Against each of these stages, weekly thresholds of rainfall and temperature, climate risks that hinder optimal development and physical responses of the crop to dynamic weather conditions (eg: dropping of flowers, shedding of leaves, underdevelopment of pods) were mapped.

In the next step, through the engagement with farmers information on climate risks manifesting at the farm level, observed impacts on crop phenology, incidence of pest and disease outbreaks and measures taken to cope or mitigate perceived impacts were obtained for the past five cropping seasons on the basis of recall.

CLIMATE ANALYSIS

Parameters:
Rainfall & Temperature

RCP:
8.5 scenario

Analysis:
Historical period (1989 – 2018) and projected future climate (2021-2050).

CROP PHENOLOGY

Undertook comprehensive literature review to identify how dynamic weather patterns impact the different stages of soybean, cotton, wheat and gram crops.

For every crop stage and corresponding month, impacts on emergence, flower development and grain formation among others was mapped out and correlated with findings from the climate analysis at monthly scale.

COMMUNITY ADAPTATION

Discussions were conducted with diverse farmer groups to understand how climate variability and change have affected farming operations, quality of produce, production and how they have been coping/responding to secure crop production over the past five agriculture seasons.

2.4 Geographical Scope

The study was conducted across 8 districts in Maharashtra (See Figure 2) where soybean, cotton, wheat and gram are the major crops.

The districts are Amravati, Aurangabad, Chandrapur, Dhule, Jalgaon, Jalna, Nanded, and Yavatmal. These districts were chosen to cover three main regions of the state namely, Vidarbha, Marathwada and Khandesh.

These regions are characterized by diverse agro-climatic conditions, soils and access to critical infrastructure such as irrigation.

The four crops namely soybean, cotton, wheat and gram were selected because these crops are commonly grown across the state, represent both Kharif (soybean and cotton) and Rabi seasons (wheat and gram) and are grown by rainfed farmers (soybean, cotton, gram) and irrigated farmers (soybean, cotton and wheat).

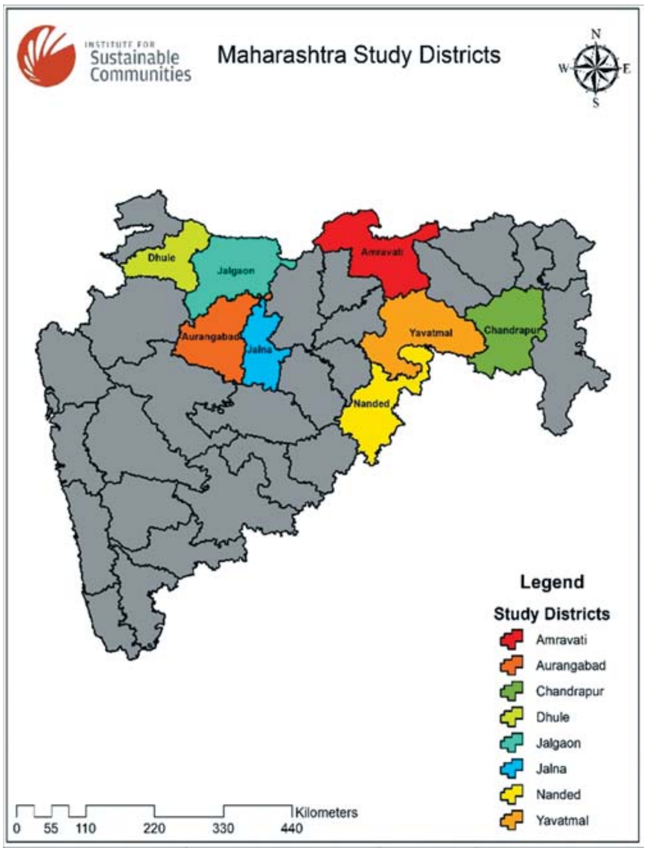


Figure 2: Geographical Scope

2.5 Scale of Analysis

The vulnerability analysis presented in this report has been examined stage wise and week wise. The purpose of undertaking the analysis at such minute scales was to situate the exposure of farmers to risks and current pressures on crop production systems in the larger context of climate change. By identifying stage wise risks and vulnerability, the aim of this report was to increase knowledge of the risks to agriculture and offer insights into support and action required by farmers for effective adaptation.

3
Findings

The findings of the study for each of the four crops - Cotton, Soybean, Wheat and Gram are indicated in this chapter. Each crop sub-section has two parts, a stagewise analysis and a summary and discussion. The stagewise analysis details out:

- Results of weekly historical climate analysis for 8 districts of Maharashtra – Dhule and Jalgaon in Khandesh, Aurangabad, Jalna and Nanded in Marathwada and Amravati, Chandrapur and Yavatmal in Vidarbha.
- Results of weekly projected climate analysis of 6 districts - Jalgaon in Khandesh, Aurangabad and Jalna in Marathwada and Amravati, Chandrapur and Yavatmal in Vidarbha for each stage of the crop.
- Observations from farmers in these regions.
- Inference summarizing how this information fits together with respect to the crop growth and development.

Each crop section culminates with a summary table of climate challenges across the cropping cycle and a discussion that links the findings to those of the greater scientific and practitioner community.

Table below shows the stages we have considered in this report for each crop.

				
CROP	**Soybean**	**Cotton**	**Wheat**	**Gram**
SEASON	**Kharif**	**Kharif**	**Rabi**	**Rabi**
DURATION	**June - October**	**June - December**	**October - March**	**October - April**
STAGES	1. Sowing and Emergence 2. Vegetative Growth 3. Flowering 4. Pod Setting & Filling 5. Maturity	1. Sowing and Vegetative growth 2. Square Formation 3. Flowering 4. Boll Setting 5. Boll Bursting	1. Sowing and Emergence 2. Tillering, Stem Elongation 3. Booting, Heading, Anthesis 4. Grain Filling 5. Maturity	1. Sowing and Emergence 2. Vegetative Growth 3. Flowering 4. Pod Formation and Filling 5. Maturity

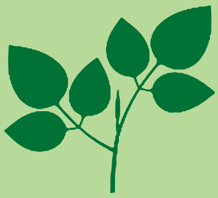
3.1 Soybean

Soybean is a short period Kharif crop, planted in June and harvested by October. The analysis and findings for each stage and overall cropping cycle is given below.

3.1.1 Stagewise Analysis

A summary of the stages of soybean is provided below:

Soybean Crop Calendar

Stage 1: Sowing and Emergence	Stage 2: Vegetative Growth	Stage 3: Flowering	Stage 4: Pod Formation and Filling	Stage 5: Maturity
				
*Week : 25,26,27 Jun weeks: 3,4 Jul weeks: 1	*Week: 28,29,30 Jul weeks: 2,3,4	*Week: 31,32,33,34 Aug weeks: 1,2,3	*Week: 35,36,37,38,39 Aug weeks: 4,5 Sept weeks: 1,2,3,4	*Week: 40,41,42 Oct weeks: 1,2,3
Seeds are planted after 100mm of monsoon rain New seedling emerges from the ground Basal fertilizer dose is applied	The stem and leaf of the plant grow Plant grows in size Second fertilizer dose, weeding and weedicide spraying occur	Buds appear and flowers bloom	Pods form from flowers Soybeans swell within the pod	Pods are fully developed and plant dries out Matured pods are harvested and further dried

** Denotes week of the year*

Stage 1

Sowing and Emergence
June – July

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 27-35 °C	Tmax: 32-34 °C	Tmax: 32-34 °C	Tmax: 32-35 °C
Tmin: 22-26 °C	Tmin: 23-24 °C	Tmin: 23-24 °C	Tmin: 24-25 °C
Rainfall: (100+)50-80 mm	Rainfall: 116 mm	Rainfall: 102-149 mm	Rainfall: 151-221 mm

Figures in Orange indicate deficit rainfall and in Blue indicate excess rainfall as compared to the optimal scenario

The optimal climatic conditions for sowing are temperatures ranging between 22 °C and 35 °C and rainfall of 100 mm before sowing and then 50-80 mm after sowing. Historical temperatures across the three regions have been within this range. Rainfall is exceedingly high in Chandrapur District and on the lower side in Dhule, Jalgaon, Aurangabad and Jalna Districts.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 25	Jun Wk 3	T max	33.80	33.95	33.56	34.17	33.69	34.50	34.90	34.90
		T min	24.30	23.78	23.14	23.82	24.12	24.25	25.05	24.69
		Rainfall	29.78	30.53	30.45	29.72	42.72	44.85	57.51	53.08
Week 26	Jun Wk4	T max	32.69	32.41	32.24	32.77	32.55	32.92	33.22	33.35
		T min	23.91	23.31	22.79	23.41	23.65	23.81	24.55	24.25
		Rainfall	45.72	44.73	38.41	38.40	56.70	53.19	81.42	65.87
Week 27	Jul Wk1	T max	31.91	31.80	31.72	32.24	31.98	32.11	32.58	32.74
		T min	23.65	23.17	22.69	23.31	23.40	23.60	24.28	24.04
		Rainfall	40.40	40.31	33.10	35.96	49.27	53.44	81.57	60.76
		Total Rainfall	115.9	115.57	101.96	104.08	148.69	151.48	220.5	179.71

Figures in Orange indicate deficit rainfall and in Blue indicate excess rainfall as compared to the optimal scenario

Future Climate Summary (2021-2050)

Climate for optimal growth:	Khandesh	Marathwada	Vidarbha
Tmax: 27-35 °C	Tmax: 31 °C	Tmax: 30-31 °C	Tmax: 30-36 °C
Tmin: 22-26 °C	Tmin: 24 °C	Tmin: 22-23 °C	Tmin: 24-26 °C
Rainfall: (100+)50-80 mm	Rainfall: 138 mm	Rainfall: 129-172 mm	Rainfall: 120-242 mm

Figures in Blue indicate excess rainfall as compared to the optimal scenario

At the time of sowing, predicted temperatures will remain well within the range of 22 °C to 35 °C. Predicted rainfall will increase in all three regions with the exception of Yavatmal in Vidarbha. This may lead to water logging in fields with poor drainage and inhibition of germination. Excess rain promotes fungal diseases, root rot and wilting in the delicate seedling stage. Rainfall in Khandesh remains lower than optimal, as well as in Aurangabad in Marathwada region and Yavatmal in Vidarbha.

Future Climate Summary (2021-2050)

Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 25	Jun Wk 3	T max	31.46	30.04	30.71	30.61	31.32	36.03
		T min	24.20	22.45	23.02	24.17	24.94	26.00
		Rainfall	37.50	36.36	47.10	55.56	73.93	35.34
Week 26	Jun Wk4	T max	31.36	29.95	30.57	30.48	31.19	34.62
		T min	23.98	22.22	22.80	23.96	24.79	25.42
		Rainfall	42.79	40.36	54.05	60.12	85.67	35.51
Week 27	Jul Wk1	T max	31.31	29.90	30.49	30.42	31.21	33.49
		T min	23.82	22.07	22.65	23.83	24.69	25.05
		Rainfall	57.48	52.48	70.85	65.44	81.95	49.40
		Total Rainfall	137.77	129.2	172	181.12	241.55	120.25

Figures in Orange indicate deficit rainfall and in Blue indicate excess rainfall as compared to the optimal scenario

Farmer Observations

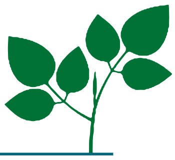
- Rising temperatures in the summer months before planting lead to hardening of the soil, increasing the effort needed to prepare the land for sowing.
- The late onset of monsoon leads to delayed sowing, which makes the crop more vulnerable to fungal diseases later on.
- Even if the monsoon begins at the expected time, a gap of 15-20 days in the rain after sowing leads to no germination and requires sowing again.
- The quality of seed is often poor due to the previous year's climatic challenges, and testing germination rates has become essential for preventing double sowing.

Inference

The sowing of soybean depends closely on the time of the onset of monsoon as well as the frequency and intensity of the monsoon. Sowing ideally takes place after 100 mm of medium intensity continuous rain has fallen, and successful germination depends on more medium intensity continuous rain after. The later the onset of monsoon, the further sowing dates are pushed, and the more vulnerable the crop becomes to fungal diseases. Erratic rainfall with several dry days in between heavier intensity rainfall will impact germination. Better drainage systems and effective rainwater harvesting become crucial to set up as soon as possible.

Stage 2

Vegetative Growth
July



Historical Climate Summary (1989-2018)

Climate for optimal growth:	Khandesh	Marathwada	Vidarbha
Tmax: 24-35 °C	Tmax: 30-31 °C	Tmax: 30-31 °C	Tmax: 30-32 °C
Tmin: 22-26 °C	Tmin: 22-23 °C	Tmin: 22-23 °C	Tmin: 23-24 °C
Rainfall: 150-200 mm	Rainfall: 120-128 mm	Rainfall: 99-168 mm	Rainfall: 174-279 mm

Figures in Orange indicate deficit rainfall and in Blue indicate excess rainfall as compared to the optimal scenario

The optimal climatic conditions for vegetative growth are temperatures ranging between 22 °C and 35 °C and rainfall of 150-200 mm. Historical temperatures across the three regions have stayed within this range. Rainfall is high in Chandrapur, and lower than optimal in Khandesh and in Aurangabad and Jalna districts of Marathwada.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 28	Jul Wk 2	T max	31.20	30.81	31.00	31.28	31.46	31.07	31.60	31.71
		T min	23.43	22.87	22.45	23.01	23.10	23.30	23.99	23.75
		Rainfall	38.04	42.22	32.85	34.37	55.53	48.77	85.78	60.17
Week 29	Jul Wk 3	T max	30.71	30.44	30.64	30.93	30.82	30.63	31.08	31.30
		T min	23.36	22.84	22.44	22.92	23.11	23.22	23.86	23.65
		Rainfall	31.39	34.73	28.12	34.31	51.50	54.14	96.86	66.49
Week 30	Jul Wk 4	T max	30.18	29.75	30.21	30.38	30.45	29.81	30.69	30.70
		T min	23.01	22.45	22.13	22.55	22.79	22.82	23.63	23.29
		Rainfall	50.17	50.83	37.95	42.65	61.44	71.49	96.25	70.34
		Total Rainfall	119.6	127.78	98.92	111.33	168.47	174.4	278.89	197

Figures in Orange indicate deficit rainfall and in Blue indicate excess rainfall as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth: Tmax: 24-35 °C Tmin: 22-26 °C Rainfall: 150-200 mm	**Khandesh** Tmax: 31-32 °C Tmin: 24 °C Rainfall: 113 mm	**Marathwada** Tmax: 30-31 °C Tmin: 22-23 °C Rainfall: 122-145 mm	**Vidarbha** Tmax: 31-33 °C Tmin: 24-25 °C Rainfall: 153-195 mm
Figures in Orange indicate deficit rainfall as compared to the optimal scenario			

At the time of vegetative growth, predicted temperatures remain within the range of 22 °C to 35 °C. Rainfall in Khandesh will decrease further, threatening healthy crop development. Rainfall in Marathwada moves closer to optimal rainfall levels with an increase in rain (but still below the optimal level), and rainfall in Vidarbha will be within the optimal range. This may reduce cases of loss in yield due to excessive vegetative growth, and benefit areas that previously did not receive enough rain.

District wise Future Climate Data (2021-2050)

Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 28	Jul Wk 2	T max	31.48	30.06	30.68	30.62	31.41	32.72
		T min	23.69	21.95	22.61	23.84	24.74	24.86
		Rainfall	46.85	42.04	44.53	52.79	64.48	61.41
Week 29	Jul Wk 3	T max	31.55	30.15	30.75	30.79	31.58	32.09
		T min	23.55	21.87	22.52	23.78	24.66	24.73
		Rainfall	39.07	41.94	52.00	56.44	73.49	60.23
Week 30	Jul Wk 4	T max	32.21	30.78	31.33	31.45	32.06	31.46
		T min	23.54	21.92	22.58	23.84	24.70	24.51
		Rainfall	27.26	37.68	47.97	43.61	57.17	69.80
		Total Rainfall	113.18	121.66	144.5	152.84	195.14	191.44

Figures in Orange indicate deficit rainfall as compared to the optimal scenario

Farmer Observations

- Vegetative growth is particularly sensitive to the amount of rainfall received.
- High rainfall during July leads to excessive vegetative growth and most of the crop never becomes stressed enough to flower or set pod.
- Excessive rainfall and flooding soon after germination leads to root rot.
- Excessive rainfall and flooding in July present a challenge during weeding and in applying the second dose of fertilizers, as women cannot enter the field to perform these actions.
- This in turn leads to increased spraying of herbicide.

Inference

Soil structure has deteriorated over the years, the soil can no longer hold and absorb water as it used to. Instead, with excessive rainfall, flooding occurs. Young plants are still delicate, and root rot and other fungal diseased set in quickly in flood conditions. During vegetative growth, 25-30 days after emergence, hoeing, weeding and a second dose of fertilizer need to take place. These tasks are usually done by women, and they find it impossible to manually weed in flooded conditions. The crop does not receive adequate fertilization and a lot of herbicide is sprayed to compensate for the lack of weeding. Also, with an increase in rainfall at this time, there is excessive vegetative growth, leading to reduced yields.

The predicted climate shows some of the extremes moving closer to the optimal rainfall of 200 mm, which may reduce these harmful effects. Some adaptations that farmers have begun to adopt are seed treatments, planting at lower density with gap rows for greater accessibility and drainage, and improving overall drainage of their holdings.

Drought stress is possible in the future, especially in Khandesh and Marathwada. Low rainfall during vegetative growth leads to an overall stunted plant, increased vulnerability to pest attacks and lowered yield.

Stage 3

Flowering
August

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 25-32 °C	Tmax: 29-30 °C	Tmax: 29-30 °C	Tmax: 29-31 °C
Tmin: 22-25 °C	Tmin: 22-23 °C	Tmin: 22 °C	Tmin: 23-24 °C
Rainfall: 40-50 mm	Rainfall: 135-174 mm	Rainfall: 146-213 mm	Rainfall: 212-339 mm

Figures in Blue indicate excess rainfall as compared to the optimal scenario

The optimal climatic conditions for soybean are temperatures ranging between 22 °C and 32 °C and rainfall of 40-50 mm. Historical temperatures in the three regions have stayed within range. Rainfall in Vidarbha has been very high during this time, and Khandesh and Marathwada are not far behind in terms of excess rainfall.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 31	Aug Wk 1	T max	29.93	29.40	29.72	30.06	30.16	29.65	30.45	30.52
		T min	22.75	22.26	21.87	22.38	22.47	22.69	23.54	23.18
		Rainfall	41.44	48.02	38.50	45.13	59.72	62.80	91.20	65.09
Week 32	Aug Wk 2	T max	29.74	29.23	29.43	29.75	30.03	29.37	30.18	30.15
		T min	22.65	22.17	21.84	22.29	22.48	22.63	23.45	23.06
		Rainfall	35.62	43.98	35.69	37.94	50.09	57.52	75.09	58.34
Week 33	Aug Wk 3	T max	29.84	29.59	29.79	30.06	29.92	29.46	30.23	30.29
		T min	22.41	22.07	21.70	22.26	22.43	22.59	23.43	23.08
		Rainfall	23.48	35.37	29.74	31.16	48.41	44.18	91.16	55.22
Week 34	Aug Wk 4	T max	29.82	29.87	30.10	30.22	29.57	29.78	30.55	30.49
		T min	22.34	21.92	21.54	22.12	22.42	22.51	23.33	22.98
		Rainfall	34.24	46.92	42.40	35.06	54.51	47.95	81.30	54.81
		Total Rainfall	134.78	174.29	146.33	149.29	212.73	212.45	338.75	233.46

Figures in Blue indicate excess rainfall as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth: Tmax: 25-32 °C Tmin: 22-25 °C Rainfall: 40-50 mm	**Khandesh** Tmax: 33-35 °C Tmin: 22-23 °C Rainfall: 113 mm	**Marathwada** Tmax: 31-34 °C Tmin: 21-23 °C Rainfall: 135-142 mm	**Vidarbha** Tmax: 31-34 °C Tmin: 23-25 °C Rainfall: 119-255 mm
Figures in Blue indicate excess rainfall as compared to the optimal scenario			

At the stage of flowering, predicted temperatures remain roughly within the optimal range of 22 °C to 32 °C. Rainfall totals remain in excess of ideal rainfall for all three regions, putting the crop at high risk to fungal disease, although predicted values are slightly lower than historical values.

District wise Future Climate Data (2021-2050)

Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 31	Aug Wk 1	T max	32.86	31.43	31.91	32.05	32.43	30.99
		T min	23.46	21.85	22.56	23.69	24.57	24.12
		Rainfall	37.69	42.99	47.00	42.11	53.18	58.62
Week 32	Aug Wk 2	T max	33.45	32.02	32.36	32.41	32.61	30.80
		T min	23.10	21.59	22.39	23.40	24.30	23.91
		Rainfall	36.12	41.25	42.97	36.05	35.62	65.39
Week 33	Aug Wk 3	T max	33.90	32.47	32.84	32.92	32.85	30.74
		T min	22.67	21.31	22.13	22.93	23.78	23.79
		Rainfall	23.58	29.22	33.63	23.86	31.83	74.02
Week 34	Aug Wk 4	T max	34.57	33.15	33.53	33.62	33.15	30.94
		T min	22.32	21.18	22.05	22.65	23.26	23.82
		Rainfall	15.60	21.11	18.82	17.10	22.83	57.39
		Total Rainfall	112.99	134.57	142.42	119.12	143.46	255.42

Figures in Blue indicate excess rainfall as compared to the optimal scenario

Farmer Observations

- High rainfall during flowering causes increased fungal diseases, necessitating pesticide sprays.
- Excess rainfall leads to reduced flowering as the plant is not sufficiently stressed.
- Flooding damages plants due to root rot.
- Low rainfall during August and September also has an adverse effect on flowering. Low rainfall leads to an increase in Jassids and Soybean rust, as well as a decrease in flowering and flowers get dropped due to water stress.

Inference

Flowering is a delicate stage for the plant where it is particularly sensitive to water stress. While historical analysis shows an average of excess rainfall, drought years commonly occur in our regions of study and have significant impacts on crops. In times of drought, flowers are shed by the plant as it cannot support flowering during the time. Since no pods develop from these dropped flowers, yield reduces overall.

In times of heavy rain, as the averages indicate, flowering soybean crops are highly vulnerable to pests and fungal disease. Some farmers mention that spraying pesticides at the time of flowering can help control these diseases and infestations sufficiently so that there is not a widespread loss of yield, but often these still have an impact on yield. Predicted rainfall is still high, and will possibly cause the same problems.

Stage 4

Pod Formation and Filling
August end- September

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 25-32 °C	Tmax: 30-32 °C	Tmax: 29-32 °C	Tmax: 30-33 °C
Tmin: 21-24 °C	Tmin: 21-22 °C	Tmin: 21-22 °C	Tmin: 22-23 °C
Rainfall: 75-100 mm	Rainfall: 159-166 mm	Rainfall: 169-191 mm	Rainfall: 175-249 mm

Figures in Blue indicate excess rainfall as compared to the optimal scenario

The optimal climatic conditions for soybean at this stage are temperatures ranging between 21 °C and 32 °C and rainfall of 75-100 mm. Historical temperatures across the three regions have stayed within range. Average rainfall is still higher than optimal, exceeding by over 100% in Chandrapur.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 35	Aug Wk 4	T max	29.78	29.71	30.14	30.12	29.47	29.77	30.48	30.42
		T min	22.29	21.81	21.41	21.95	22.22	22.42	23.28	22.86
		Rainfall	36.29	42.98	38.09	42.80	58.34	50.38	83.30	55.44
Week 36	Sep Wk 1	T max	29.76	30.17	30.49	30.55	29.53	30.31	31.08	31.05
		T min	21.91	21.57	21.16	21.81	22.08	22.38	23.34	22.91
		Rainfall	34.33	35.16	36.23	35.73	37.87	43.77	58.50	40.12
Week 37	Sep Wk 2	T max	30.19	30.92	31.01	31.19	29.62	31.21	31.61	31.76
		T min	21.84	21.60	21.22	21.89	21.99	22.33	23.29	22.88
		Rainfall	31.22	29.79	34.32	32.97	37.88	30.86	49.73	35.90
Week 38	Sep Wk 3	T max	30.03	31.17	31.12	31.46	29.67	31.48	31.94	32.04
		T min	21.67	21.56	21.24	21.85	21.80	22.13	23.19	22.78
		Rainfall	33.53	38.37	38.94	37.77	35.10	32.98	36.88	33.65
Week 39	Sep Wk 4	T max	30.62	32.07	31.91	32.35	30.10	32.53	32.86	33.00
		T min	21.39	21.57	21.27	21.78	21.46	21.91	23.02	22.61
		Rainfall	23.64	19.85	22.02	20.04	21.69	17.12	20.86	17.87
		Total Rainfall	159.01	166.15	169.6	169.31	190.88	175.11	249.27	182.98

Figures in Blue indicate excess rainfall as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 25-32 °C	Tmax: 34-35 °C	Tmax: 32-34 °C	Tmax: 31-34 °C
Tmin: 21-24 °C	Tmin: 18-22 °C	Tmin: 17-22 °C	Tmin: 19-24 °C
Rainfall: 75-100 mm	Rainfall: 20 mm	Rainfall: 29-33 mm	Rainfall: 24-227 mm

Figures in Orange indicate deficit rainfall, in Blue indicate excess rainfall, in Brown indicate higher temperatures and in Green indicate lower temperatures as compared to the optimal scenario

At the time of vegetative growth, there is a dramatic change in rainfall. Rainfall is predicted to drop drastically to levels far lower than optimal, with the exception of Yavatmal in Vidarbha which has higher than optimal rainfall. If rainfall is in the range of 10-25 mm in the future, yield will be heavily impacted as drought at this stage leads to reduced seed filling. Maximum temperatures exceed the range for optimal growth, and minimum temperatures fall below optimal range. This may impact pod filling.

District wise Future Climate Data (2021-2050)

Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 35	Aug Wk 4	T max	35.01	33.65	33.98	34.03	33.38	31.09
		T min	21.70	20.67	21.58	21.96	22.49	23.75
		Rainfall	10.41	12.67	12.94	10.81	13.70	63.21
Week 36	Sep Wk 1	T max	34.97	33.62	33.90	33.93	33.29	31.68
		T min	20.78	19.84	20.77	21.05	21.72	23.82
		Rainfall	3.86	6.38	10.15	6.65	10.21	48.93
Week 37	Sep Wk 2	T max	34.69	33.36	33.59	33.61	32.97	32.15
		T min	19.87	19.01	19.98	20.23	20.80	23.72
		Rainfall	3.28	5.15	5.21	3.89	6.60	47.67
Week 38	Sep Wk 3	T max	34.18	32.85	33.12	33.16	32.50	32.46
		T min	18.83	18.05	19.03	19.31	19.53	23.50
		Rainfall	1.89	3.26	3.25	1.39	3.28	38.52
Week 39	Sep Wk 4	T max	33.52	32.24	32.57	32.57	32.02	32.82
		T min	18.06	17.29	18.27	18.54	18.52	23.06
		Rainfall	0.95	2.01	1.64	1.20	0.67	29.03
		Total Rainfall	20.39	29.47	33.19	23.94	34.46	227.36

Figures in Orange indicate deficit rainfall, in Blue indicate excess rainfall, in Brown indicate higher temperatures and in Green indicate lower temperatures as compared to the optimal scenario

Farmer Observations

- Low rainfall during podding and seed filling leads to reduced seed filling.
- Rising temperatures during September and October also lead to reduced seed filling.
- In Amravati, a rise in temperature has been noted, leading to low yields.

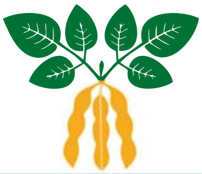
Inference

As mentioned above, while historical averages show an excess of rainfall during the pod formation and filling stages, frequent droughts have led farmers to observe that a lack of water during pod filling leads to decreased yields. Again, since the soil can no longer hold as much water as it once could, sufficient rainfall in the previous months does not translate to adequate soil moisture during this time. Soybeans within pods do not swell up as much, and are smaller, translating to an overall lower yield and lower price received for it. The predicted rainfall is shockingly low at this time, and will certainly lead to significant soybean yield losses if climate continues to follow this pattern. Crops raised at such low soil moisture are susceptible to Soybean rust, which is increasing in prevalence in our regions of study and affecting large proportions of planted soybean.

In the case of excess rainfall, crops may not reach the pod formation stage at all. They continue with excess vegetative growth, never being stressed enough to flower and fruit. Some plants that do set pod never sufficiently dry out, and the pods fall victim to fungal diseases. Diseased pods have greater processing costs associated, and lead to a loss in profit. Increased spraying of pesticides is the path many farmers take to combat this.

Stage 5

Maturity
October



Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 30-36 °C	Tmax: 31-33 °C	Tmax: 30-33 °C	Tmax: 33 °C
Tmin: 20-23 °C	Tmin: 19-20 °C	Tmin: 19-20 °C	Tmin: 20-21 °C
Rainfall: 0-10 mm	Rainfall: 35-39 mm	Rainfall: 52-67 mm	Rainfall: 42-51 mm

Figures in Blue indicate excess rainfall and in Green indicate lower temperatures as compared to the optimal scenario

The optimal climatic conditions for soybean are temperatures ranging between 20 °C and 36 °C and rainfall of 0-10 mm. Historical maximum temperatures across the three regions have stayed within range, historical minimum temperatures dip slightly below the optimal range, However rainfall exceeds required amount significantly. Rainfall during physical maturity can decimate yields.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 40	Oct Wk 1	T max	31.19	33.00	32.57	32.88	30.21	33.09	33.03	33.29
		T min	21.15	21.24	20.98	21.46	21.21	21.56	22.62	22.27
		Rainfall	14.15	15.50	19.52	23.69	27.16	18.25	23.01	23.22
Week 41	Oct Wk 2	T max	31.12	33.23	32.90	33.00	30.17	33.02	33.13	33.33
		T min	20.65	20.74	20.40	20.87	20.73	20.80	21.96	21.56
		Rainfall	14.67	17.05	22.84	22.03	18.95	15.36	15.49	13.73
Week 42	Oct Wk 3	T max	31.44	33.35	32.96	32.95	30.11	32.89	32.88	33.14
		T min	19.42	19.29	19.08	19.49	19.33	19.37	20.77	20.26
		Rainfall	6.11	6.88	9.81	10.71	20.89	8.04	12.56	11.58
		Total Rainfall	34.93	39.43	52.17	56.43	67	41.65	51.06	48.53

Figures in Blue indicate excess rainfall and in Green indicate lower temperatures as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 30-36 °C	Tmax: 32-33 °C	Tmax: 31-32 °C	Tmax: 30-34 °C
Tmin: 20-23 °C	Tmin: 15-17 °C	Tmin: 15-18 °C	Tmin: 16-23 °C
Rainfall: 0-10 mm	Rainfall: 2 mm	Rainfall: 3 mm	Rainfall: 2-43 mm

Figures in Blue indicate excess rainfall and in Green indicate lower temperatures as compared to the optimal scenario

At the time of maturity, predicted maximum temperatures remain within 36 °C, but minimum temperatures dip below 20 °C and go down to 15-16 °C in all three regions, with the exception of Yavatmal district. Amount of rainfall received is predicted to reduce till almost none, except in Yavatmal. This may benefit many farmers by avoiding loss due to rain at the time of physical maturity of the crop. Yavatmal farmers will still be at risk.

District wise Future Climate Data (2021-2050)								
Week of the Year	**Month & Week**	**Variable**	**Khandesh**	**Marathwada**		**Vidarbha**		
			Jalgaon	**Aurangabad**	**Jalna**	**Amravati**	**Chandrapur**	**Yavatmal**
Week 40	Oct Wk 1	T max	32.89	31.67	31.97	31.78	31.40	33.30
		T min	17.33	16.63	17.54	17.68	17.50	22.77
		Rainfall	0.42	1.26	1.22	0.98	0.62	21.83
Week 41	Oct Wk 2	T max	32.28	31.17	31.46	31.07	30.84	33.67
		T min	16.09	15.50	16.46	16.49	16.34	22.10
		Rainfall	0.90	1.25	1.82	0.80	0.79	12.98
Week 42	Oct Wk 3	T max	31.80	30.81	31.09	30.55	30.47	33.56
		T min	15.31	14.81	15.74	15.64	15.55	21.31
		Rainfall	0.34	0.61	0.35	0.76	0.13	8.68
		Total Rainfall	1.66	3.12	3.39	2.54	1.54	43.49

Figures in Green indicate lower temperatures and in Blue indicate excess rainfall as compared to the optimal scenario

Farmer Observations

- The most devastating loss for soybean, in farmers' experiences, occurs during harvesting.
- Untimely rainfall during October end/November damages the plants that have reached maturity and are ready to harvest.
- Often they germinate in response to the rainfall inside the pod itself, and intact pods develop a high incidence of fungal diseases.
- At this point, there is nothing the farmer can do to recover the yield.
- Post-threshing costs increase, yields are reduced and profit is reduced.
- The remaining seeds to be planted the next year are also damaged.

Inference

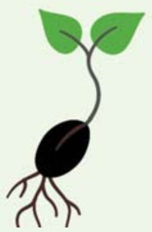
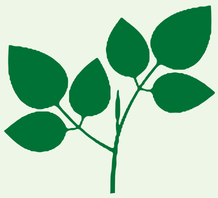
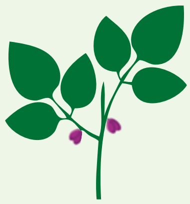
Farmers stated that rain during the time of harvest was one of the greatest climate related challenges they faced. For those who cultivated shorter duration soybean, their yield was mostly lost in rainfall during the end of September and early October. Most farmers harvest soybean crops and lay them in the field, right next to where they are cut, to dry out. If it rains during this time, yield are devastated. Pods rot and fall victim to fungal diseases.

Since the soybean pod is on the thinner side, many soybeans absorb water and begin to sprout through the pod. Such beans are lost yield. If farmers are able to harvest and thresh pods before it rains, often they do not have the ability to store the beans in a waterproof fashion. These seeds also get fungal diseases, and profits are greatly reduced. The predicted rainfall during this stage is very low, and hopefully farmers will not have to face this problem in the future. Currently, farmers have adapted by growing less soybean in proportion to other crops, growing longer duration varieties and harvesting early if rain is forecasted.

3.1.2 Summary and Discussion

A summary of the climate risks found through climate analyses and farmer validation is given below:

Summary of Climate Effects

Stage 1: Sowing and Emergence	Stage 2: Vegetative Growth	Stage 3: Flowering	Stage 4: Pod Formation and Filling	Stage 5: Maturity
*Week : 25,26,27 Jun weeks: 3,4 Jul weeks: 1	*Week: 28,29,30 Jul weeks: 2,3,4	*Week: 31,32,33,34 Aug weeks: 1,2,3	*Week: 35,36,37,38,39 Aug weeks: 4,5 Sept weeks: 1,2,3,4	*Week: 40,41,42 Oct weeks: 1,2,3
				
PRESENT CLIMATE RISKS				
Late onset of monsoon Excess rainfall Inadequate rainfall	Excess rainfall and flooding	Excess rainfall and flooding	Excess rainfall	Rainfall destroying harvest
IMPACTS				
Double sowing Low germination	Difficulty in weeding Difficulty in fertilizer application Reduced plant yield and growth application	Increased fungal diseases and pests Low flowering	Increased fungal diseases and pests	Loss of grain in field Loss of harvested grain
ADAPTATIONS				
Germination testing Seed treatment	Increased herbicide spraying	Increased pesticide spraying	Increased pesticide spraying	Early harvesting Using long duration varieties
FUTURE CLIMATE RISKS				
Excess rainfall in some places	Excess rainfall	Inadequate rainfall	Inadequate rainfall	Highly inadequate rainfall

** Denotes week of the year*

Discussion

Rainfall impacted the soybean crop cycle negatively in several ways. High rainfall during June, July and August caused increasing incidence of fungal diseases. A wet and warm environment is favourable to pests – the white fly, spodoptera and the soybean semilooper. Degraded soil structure combined with heavy rainfall leads to flooding, which promotes root rot and fungal diseases, as well as impedes crucial processes like weeding and supplemental fertilization. Studies show that the late onset of monsoon, prolonged dry spell during growth stages, early cessation of monsoon, and damage to the crop during maturity period are particularly harmful.

An increase in extreme rain events is detrimental to the crop as soybean is intolerant of flooding. The predicted changes in rainfall will exacerbate existing challenges. Inadequate rain during the vegetative period leads to weak vegetative growth, then excess rain during flowering will lead to an increase in diseases, root rot and pests until August, and then the sudden drop in rainfall during the important stage of pod filling lead to reduced pod filling and inferior quality soybean.

Rising cost of inputs as well as increasing amounts of inputs required contribute to the rising total cost of cultivation. Additionally, all soybean crops in an area mature at the same time, close to the time of the first picking of cotton, and so harvesting labour is difficult to obtain and expensive. Farmers in some parts of Vidarbha have chosen to plant pigeon pea or cotton instead, while farmers in Marathwada have no choice but to continue growing soybean as cotton market networks are not well developed in the area. Due to the short period of the crop, farmers feel that there is not adequate time to deal with the effects of disruptive climate events – even a short spell of intense rain can lead to crop losses, with no time to recover. Figuring out a way to balance early excess rain and later sparse rainfall predicted in the future will be key to continued cultivation of soybean.

Overall, the main climatic factor that caused yield loss at present was rainfall, and not temperature. From both historical and projected analyses, temperatures did not play a major role. They did not change much in the three study regions, and remained mostly within ideal ranges. Many studies have been conducted on the effects of rising temperatures on soybean cultivation, and they have found effects such as reduction of yield through harm to the reproductive system – flowering, pod formation and filling – and also through the change in timings of stage, shortening vegetative growth and pod filling, and increasing flowering time.

Farmers across the three regions did not observe any such changes in timings, as there are many factors influencing progression of the crop, such as the variety grown, the nutrition and resources available and so on. The only observed difference between ideal temperatures and predicted temperatures was the dropping of minimum temperatures during maturity from 20 °C to 15 °C. Ideally, a hot and sunny climate is beneficial at the time do facilitate drying of harvested pods, but since the maximum temperatures are not reducing much, this may not negatively affect crops. Heat at the time of harvesting leads to heat strain and itchiness in women who are harvesting, so slightly lowered maximum temperatures may benefit them.

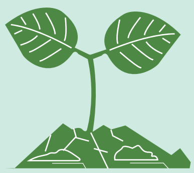
3.2 Cotton

Cotton is a long-duration Kharif crop, sown in June and harvested from November through February. The analysis and findings for each stage and overall cropping cycle is given below.

3.2.1 Stagewise Analysis

A summary of the stages of cotton is provided below:

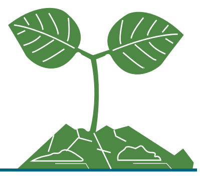
Cotton Crop Calendar

Stage 1: Sowing and Vegetative Growth	Stage 2: Square Formation	Stage 3: Flowering	Stage 4: Boll Setting	Stage 5: Boll Bursting
				
*Week: 23,24,25,26,27,28 Jun weeks: 1,2,3,4 Jul weeks: 1,2	*Week: 29,30,31,32,33,34,35 Jul weeks: 3,4 Aug weeks: 1,2,3,4,5	*Week: 36,37,38,39 Sep weeks: 1,2,3,4	*Week: 40,41,42,43 Oct weeks: 1,2,3,4	*Week: 44,45,46,47,48,49 Nov weeks: 1,2,3,4,5 Dec weeks: 1
Seeds are planted New seedling emerges from the ground Stem, leaves and roots develop and the plant grows in size	The reproductive phase begins with the development of squares (Squares are the buds of the cotton plant) Squares grow in size	Squares bloom into flowers	The fruit of the cotton crop – the cotton boll is formed The boll contains seeds embedded in soft fibers, and it increases in volume	Cotton bolls burst open revealing the fluffy lint Opened bolls are harvested by plucking them from the plant Several rounds of harvesting take place as bolls mature at different times

** Denotes week of the year*

Stage 1

Sowing and Vegetative Growth
June-July



Historical Climate Summary (1989-2018)

Climate for optimal growth:	Khandesh	Marathwada	Vidarbha
Tmax: 30-36 °C	Tmax: 31-38 °C	Tmax: 31-38 °C	Tmax: 31-40 °C
Tmin: 20-23 °C	Tmin: 23-25 °C	Tmin: 22-27 °C	Tmin: 23-27 °C
Rainfall: 80 mm	Rainfall: 201-212 mm	Rainfall: 196-280 mm	Rainfall: 268-387 mm

Figures in Blue indicate excess rainfall and in Brown indicate higher temperatures as compared to the optimal scenario

Maximum temperatures, minimum temperatures and rainfall all exceed the range for optimal growth during the sowing and vegetative growth period. Exceeding maximum temperatures are not likely to have had too much of an effect on this stage as they occur mostly in the first week of June, when fewer farmers have begun planting. Minimum temperatures exceed 23 °C almost throughout this phase, but more in Khandesh and Vidarbha than in Marathwada. Rainfall is highly in excess of the amount needed for optimal growth, and is nearly four times the required amount in Chandrapur district.

District wise Historical Climate Data (1989-2018)										
Week of the Year	**Month & Week**	**Variable**	**Khandesh**		**Marathwada**			**Vidarbha**		
			Dhule	**Jalgaon**	**Aurangabad**	**Jalna**	**Nanded**	**Amravati**	**Chandrapur**	**Yavatmal**
Week 23	Jun Wk 1	T max	37.83	37.87	37.21	38.16	38.14	39.24	39.94	39.62
		T min	25.20	24.87	24.04	25.12	26.77	26.19	27.21	26.62
		Rainfall	16.80	22.04	27.64	29.48	26.49	18.24	22.47	22.05
Week 24	Jun Wk 2	T max	35.31	35.51	35.00	35.65	34.85	36.57	37.18	36.87
		T min	24.79	24.16	23.46	24.20	25.00	24.94	25.92	25.34
		Rainfall	30.68	32.04	33.45	36.72	49.26	49.13	58.16	56.77
Week 25	Jun Wk 3	T max	33.80	33.95	33.56	34.17	33.69	34.50	34.90	34.90
		T min	24.30	23.78	23.14	23.82	24.12	24.25	25.05	24.69
		Rainfall	29.78	30.53	30.45	29.72	42.72	44.85	57.51	53.08
Week 26	Jun Wk 4	T max	32.69	32.41	32.24	32.77	32.55	32.92	33.22	33.35
		T min	23.91	23.31	22.79	23.41	23.65	23.81	24.55	24.25
		Rainfall	45.72	44.73	38.41	38.40	56.70	53.19	81.42	65.87
Week 27	Jul Wk 1	T max	31.91	31.80	31.72	32.24	31.98	32.11	32.58	32.74
		T min	23.65	23.17	22.69	23.31	23.40	23.60	24.28	24.04
		Rainfall	40.40	40.31	33.10	35.96	49.27	53.44	81.57	60.76
Week 28	Jul Wk 2	T max	31.20	30.81	31.00	31.28	31.46	31.07	31.60	31.71
		T min	23.43	22.87	22.45	23.01	23.10	23.30	23.99	23.75
		Rainfall	38.04	42.22	32.85	34.37	55.53	48.77	85.78	60.17
		Total Rainfall	201.42	211.87	195.9	204.65	279.97	267.62	386.91	318.7

Figures in Blue indicate excess rainfall and in Brown indicate higher temperatures as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 30-36 °C	Tmax: 31-32 °C	Tmax: 30-32 °C	Tmax: 30-40 °C
Tmin: 20-23 °C	Tmin: 24-25 °C	Tmin: 22-24 °C	Tmin: 24-28 °C
Rainfall: 80 mm	Rainfall: 263 mm	Rainfall: 242-301 mm	Rainfall: 239-462 mm

Figures in Blue indicate excess rainfall and in Brown indicate higher temperatures as compared to the optimal scenario

Similar to the historical averages, minimum temperatures exceed the range for optimal growth. In the projected climate, minimum temperatures exceed optimal throughout the six week period of sowing and vegetative growth in Khandesh and Vidarbha. Rainfall exceeds the optimal amount by a greater margin than the historical average, which will be a problem for cotton crops in the future. Maximum temperatures exceed the range for optimal growth only in Yavatmal district during the first two weeks, which is likely to be beneficial for the crop.

District wise Future Climate Data (2021-2050)								
Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 23	Jun Wk 1	T max	32.39	30.86	31.59	31.80	32.39	40.19
		T min	24.69	22.97	23.60	24.76	25.55	28.01
		Rainfall	36.82	31.71	36.61	58.64	74.92	25.12
Week 24	Jun Wk 2	T max	31.80	30.34	31.06	31.13	31.82	38.20
		T min	24.50	22.79	23.39	24.54	25.33	26.96
		Rainfall	41.60	38.56	48.29	65.04	81.55	32.47
Week 25	Jun Wk 3	T max	31.46	30.04	30.71	30.61	31.32	36.03
		T min	24.20	22.45	23.02	24.17	24.94	26.00
		Rainfall	37.50	36.36	47.10	55.56	73.93	35.34
Week 26	Jun Wk 4	T max	31.36	29.95	30.57	30.48	31.19	34.62
		T min	23.98	22.22	22.80	23.96	24.79	25.42
		Rainfall	42.79	40.36	54.05	60.12	85.67	35.51
Week 27	Jul Wk 1	T max	31.31	29.90	30.49	30.42	31.21	33.49
		T min	23.82	22.07	22.65	23.83	24.69	25.05
		Rainfall	57.48	52.48	70.85	65.44	81.95	49.40
Week 28	Jul Wk 1	T max	31.48	30.06	30.68	30.62	31.41	32.72
		T min	23.69	21.95	22.61	23.84	24.74	24.86
		Rainfall	46.85	42.04	44.53	52.79	64.48	61.41
		Total Rainfall	263.04	241.51	301.43	357.59	462.5	239.25
Figures in Blue indicate excess rainfall and in Brown indicate higher temperatures as compared to the optimal scenario								

Farmer Observations

- Late onset of monsoon leads to germination loss and requires double sowing.
- There are incidences of dry spell after the start of the monsoon.
- Heavy rainfall at times have also damaged the saplings.
- Increased temperatures and erratic rainfall cause increased pest and disease attacks.
- Heavy rainfall causes water logging, weeding cannot take place, and herbicide spraying is increased.

Inference

At the time of sowing and vegetative growth, rainfall is historically in excess of the amount needed for optimal growth, and the future projection shows that it will increase to be in greater excess than historical. This poses a serious problem, as high rainfall leads to water logging, which in turn promotes fungal diseases. Farmers have noted that the rain is erratic – heavy rain for a spell and some then no rain for a spell, and this impacts young plants and germinating seedlings. While the vegetative parts of the plant are more resistant to rising temperatures, the higher than optimal temperatures promote pests, and cause infestations. Cotton is associated with heavy pesticide use, and high temperatures and erratic rainfall promote pests from a very early stage.

Stage 2

Square Formation
July - August

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 28-33 °C	Tmax: 29-31 °C	Tmax: 29-31 °C	Tmax: 29-31 °C
Tmin: 20-24 °C	Tmin: 22-23 °C	Tmin: 21-23 °C	Tmin: 22-24 °C
Rainfall: 111 mm	Rainfall: 253-303 mm	Rainfall: 250-384 mm	Rainfall: 388-615 mm
Figures in Blue indicate excess rainfall as compared to the optimal scenario			

During square formation, historical temperature has remained within the range for optimal growth. Rainfall, however, exceeds the amount needed for optimal growth. Chandrapur district has 5-6 times the required amount of rainfall, and all districts have at least twice the amount of rainfall required.

District wise Historical Climate Data (1989-2018)										
Week of the Year	**Month & Week**	**Variable**	**Khandesh**		**Marathwada**			**Vidarbha**		
			Dhule	**Jalgaon**	**Aurangabad**	**Jalna**	**Nanded**	**Amravati**	**Chandrapur**	**Yavatmal**
Week 29	Jul Wk 3	T max	30.71	30.44	30.64	30.93	30.82	30.63	31.08	31.30
		T min	23.36	22.84	22.44	22.92	23.11	23.22	23.86	23.65
		Rainfall	31.39	34.73	28.12	34.31	51.50	54.14	96.86	66.49
Week 30	Jul Wk 4	T max	30.18	29.75	30.21	30.38	30.45	29.81	30.69	30.70
		T min	23.01	22.45	22.13	22.55	22.79	22.82	23.63	23.29
		Rainfall	50.17	50.83	37.95	42.65	61.44	71.49	96.25	70.34
Week 31	Aug Wk 1	T max	29.93	29.40	29.72	30.06	30.16	29.65	30.45	30.52
		T min	22.75	22.26	21.87	22.38	22.47	22.69	23.54	23.18
		Rainfall	41.44	48.02	38.50	45.13	59.72	62.80	91.20	65.09
Week 32	Aug Wk 2	T max	29.74	29.23	29.43	29.75	30.03	29.37	30.18	30.15
		T min	22.65	22.17	21.84	22.29	22.48	22.63	23.45	23.06
		Rainfall	35.62	43.98	35.69	37.94	50.09	57.52	75.09	58.34
Week 33	Aug Wk 3	T max	29.84	29.59	29.79	30.06	29.92	29.46	30.23	30.29
		T min	22.41	22.07	21.70	22.26	22.43	22.59	23.43	23.08
		Rainfall	23.48	35.37	29.74	31.16	48.41	44.18	91.16	55.22
Week 34	Aug Wk 4	T max	29.82	29.87	30.10	30.22	29.57	29.78	30.55	30.49
		T min	22.34	21.92	21.54	22.12	22.42	22.51	23.33	22.98
		Rainfall	34.24	46.92	42.40	35.06	54.51	47.95	81.30	54.81
Week 35	Aug Wk 5	T max	29.78	29.71	30.14	30.12	29.47	29.77	30.48	30.42
		T min	22.29	21.81	21.41	21.95	22.22	22.42	23.28	22.86
		Rainfall	36.29	42.98	38.09	42.80	58.34	50.38	83.30	55.44
		Total Rainfall	252.63	302.83	250.49	269.05	384.01	388.46	615.16	425.73
Figures in Blue indicate excess rainfall as compared to the optimal scenario										

Future Climate Summary (2021-2050)			
Climate for optimal growth: Tmax: 28-33 °C Tmin: 20-24 °C Rainfall: 111 mm	**Khandesh** Tmax: 32-35 °C Tmin: 22-24 °C Rainfall: 190 mm	**Marathwada** Tmax: 30-34 °C Tmin: 21-23 °C Rainfall: 227-255 mm	**Vidarbha** Tmax: 31-34 °C Tmin: 22-25 °C Rainfall: 230-449 mm
Figures in Brown indicate higher temperatures and in Blue indicate excess rainfall as compared to the optimal scenario			

The ranges of temperatures predicted in the future during the weeks of square formation are higher than historical ones. In all three regions, maximum temperatures are slightly higher than optimal towards the end of August, at the end of this stage. Minimum temperatures are within range in Khandesh and Marathwada, but exceed the range for optimal growth in Chandrapur and Yavatmal districts of Vidarbha during the first few weeks of this stage. Rainfall exceeds the optimal amount, but no longer by as large a margin as in historical rainfall averages. Yavatmal district has the highest rainfall of about 4 times the required amount.

District wise Future Climate Data (2021-2050)

Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 29	Jul Wk 3	T max	31.55	30.15	30.75	30.79	31.58	32.09
		T min	23.55	21.87	22.52	23.78	24.66	24.73
		Rainfall	39.07	41.94	52.00	56.44	73.49	60.23
Week 30	Jul Wk 4	T max	32.21	30.78	31.33	31.45	32.06	31.46
		T min	23.54	21.92	22.58	23.84	24.70	24.51
		Rainfall	27.26	37.68	47.97	43.61	57.17	69.80
Week 31	Aug Wk 1	T max	32.86	31.43	31.91	32.05	32.43	30.99
		T min	23.46	21.85	22.56	23.69	24.57	24.12
		Rainfall	37.69	42.99	47.00	42.11	53.18	58.62
Week 32	Aug Wk 2	T max	33.45	32.02	32.36	32.41	32.61	30.80
		T min	23.10	21.59	22.39	23.40	24.30	23.91
		Rainfall	36.12	41.25	42.97	36.05	35.62	65.39
Week 33	Aug Wk 3	T max	33.90	32.47	32.84	32.92	32.85	30.74
		T min	22.67	21.31	22.13	22.93	23.78	23.79
		Rainfall	23.58	29.22	33.63	23.86	31.83	74.02
Week 34	Aug Wk 4	T max	34.57	33.15	33.53	33.62	33.15	30.94
		T min	22.32	21.18	22.05	22.65	23.26	23.82
		Rainfall	15.60	21.11	18.82	17.10	22.83	57.39
Week 35	Aug Wk 5	T max	35.01	33.65	33.98	34.03	33.38	31.09
		T min	21.70	20.67	21.58	21.96	22.49	23.75
		Rainfall	10.41	12.67	12.94	10.81	13.70	63.21
		Total Rainfall	189.73	226.86	255.33	229.98	287.82	448.66

Figures in Brown indicate higher temperatures and in Blue indicate excess rainfall as compared to the optimal scenario

Farmer Observations

- Farmers have noted an increase in humidity during this period. This is due to high rainfall and temperature and the dense foliage of the plant at this stage. As a result, there are increased pest attacks.
- Rising temperatures lead to squares being dropped from the plant.
- Root rot and wilt affect plant growth and plants dye from water stress.

Inference

The consequences of excess rainfall during the square formation period are serious and impact yield. Pest attacks and diseases increase, impacting yield. The more dire consequence is the death of plants due to water stress from water logging. In addition to this, high temperatures cause squares to be dropped and contribute to creating a humid environment that pests thrive in. Future climate projections show a continued excess of rainfall and even higher temperatures, and ways to reduce their impact on square formation must be found.

Stage 3

Flowering
September

Historical Climate Summary (1989-2018)

Climate for optimal growth:	Khandesh	Marathwada	Vidarbha
Tmax: 30-33 °C	Tmax: 30-32 °C	Tmax: 30-32 °C	Tmax: 30-33 °C
Tmin: 20-23 °C	Tmin: 21-22 °C	Tmin: 21-22 °C	Tmin: 22-23 °C
Rainfall: 222 mm	Rainfall: 123 mm	Rainfall: 127-133 mm	Rainfall: 125-166 mm

Figures in Orange indicate deficit rainfall as compared to the optimal scenario

During the stage of flowering, temperature maximum and minimums have historically been within the range required for optimal growth. In a trend opposite to the last two stages, rainfall is less than required in all three regions.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 36	Sep Wk 1	T max	29.76	30.17	30.49	30.55	29.53	30.31	31.08	31.05
		T min	21.91	21.57	21.16	21.81	22.08	22.38	23.34	22.91
		Rainfall	34.33	35.16	36.23	35.73	37.87	43.77	58.50	40.12
Week 37	Sep Wk 2	T max	30.19	30.92	31.01	31.19	29.62	31.21	31.61	31.76
		T min	21.84	21.60	21.22	21.89	21.99	22.33	23.29	22.88
		Rainfall	31.22	29.79	34.32	32.97	37.88	30.86	49.73	35.90
Week 38	Sep Wk 3	T max	30.03	31.17	31.12	31.46	29.67	31.48	31.94	32.04
		T min	21.67	21.56	21.24	21.85	21.80	22.13	23.19	22.78
		Rainfall	33.53	38.37	38.94	37.77	35.10	32.98	36.88	33.65
Week 39	Sep Wk 4	T max	30.62	32.07	31.91	32.35	30.10	32.53	32.86	33.00
		T min	21.39	21.57	21.27	21.78	21.46	21.91	23.02	22.61
		Rainfall	23.64	19.85	22.02	20.04	21.69	17.12	20.86	17.87
		Total Rainfall	122.72	123.17	131.51	126.51	132.54	124.73	165.97	127.54

Figures in Orange indicate deficit rainfall as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth: Tmax: 30-33 °C Tmin: 20-23 °C Rainfall: 222 mm	**Khandesh** Tmax: 34-35 °C Tmin: 18-21 °C Rainfall: 10 mm	**Marathwada** Tmax: 32-34 °C Tmin: 17-21 °C Rainfall: 17-20 mm	**Vidarbha** Tmax: 32-34 °C Tmin: 19-24 °C Rainfall: 13-164 mm

Figures in Orange indicate deficit rainfall, in Brown indicate higher temperatures and in Green indicate lower temperatures as compared to the optimal scenario

The future temperatures during flowering fall slightly outside the maximum and minimum ranges. In all three regions, maximum temperatures are slightly higher than optimal, and minimum temperatures go below ideal. The crop is likely to be exposed to a greater range of temperature overall. In Yavatmal district, minimum temperatures also rise higher than optimal. Rainfall is much less than the amount required for optimal growth, except in Yavatmal district.

District wise Future Climate Data (2021-2050)

Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 36	Sep Wk 1	T max	34.97	33.62	33.90	33.93	33.29	31.68
		T min	20.78	19.84	20.77	21.05	21.72	23.82
		Rainfall	3.86	6.38	10.15	6.65	10.21	48.93
Week 37	Sep Wk 2	T max	34.69	33.36	33.59	33.61	32.97	32.15
		T min	19.87	19.01	19.98	20.23	20.80	23.72
		Rainfall	3.28	5.15	5.21	3.89	6.60	47.67
Week 31	Sep Wk 3	T max	34.18	32.85	33.12	33.16	32.50	32.46
		T min	18.83	18.05	19.03	19.31	19.53	23.50
		Rainfall	1.89	3.26	3.25	1.39	3.28	38.52
Week 39	Sep Wk 4	T max	33.52	32.24	32.57	32.57	32.02	32.82
		T min	18.06	17.29	18.27	18.54	18.52	23.06
		Rainfall	0.95	2.01	1.64	1.20	0.67	29.03
		Total Rainfall	9.98	16.8	20.25	13.13	20.76	164.15

Figures in Orange indicate deficit rainfall, in Brown indicate higher temperatures and in Green indicate lower temperatures as compared to the optimal scenario

Farmer Observations

- High intensity rainfall has been noted during this time, which leads to water logging and its associated problems.
- Erratic rainfall and with fog causes proliferation of pests and disease.
- Strong winds at this time may cause plants to fall over damaging the flowers.
- High temperatures at this time may cause flowers to drop or impede development of bolls from flowers.

Inference

Flowering in cotton is affected by both temperature and rainfall. Flowering is the beginning of the sensitive reproductive stage, and these climatic events affect flowering. Erratic rainfall ranging from intense rainfall to dry spells causes stress in the plant, and water logging causes root damage and rot. Historical averages are already below the amount required for optimal growth, but the rainfall pattern is erratic, and water logging is caused by short intense spells of rain rather than an excess of rainfall. High temperatures cause flowers to drop, or prevent bolls developing from flowers. This directly impacts yield. From future predictions, we see that the average total rainfall received during this stage will drop, possibly exposing the plant to more stress due to reduced soil moisture. Temperatures are predicted to rise slightly, which will further impact flowers and bolls. The combination of high temperature and heavy rainfall spells promote pests and will probably continue to do so in the future which is likely to impact the growth and development of the crop.

Stage 4

Boll Setting
October

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 28-32 °C	Tmax: 31-33 °C	Tmax: 30-33 °C	Tmax: 32-33 °C
Tmin: 20-23 °C	Tmin: 18-21 °C	Tmin: 18-21 °C	Tmin: 18-23 °C
Rainfall: 380 mm	Rainfall: 38-44 mm	Rainfall: 57-76 mm	Rainfall: 48-58 mm

Figures in Orange indicate deficit rainfall, in Brown indicate higher temperatures and in Green indicate lower temperatures as compared to the optimal scenario

During boll setting, maximum temperatures slightly exceed the range for optimal growth in all three regions. Minimum temperatures reach below the optimal range in all districts by the end of October. Rainfall is far below the optimal amount, which has probably impacted yields so far.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 40	Oct Wk 1	T max	31.19	33.00	32.57	32.88	30.21	33.09	33.03	33.29
		T min	21.15	21.24	20.98	21.46	21.21	21.56	22.62	22.27
		Rainfall	14.15	15.50	19.52	23.69	27.16	18.25	23.01	23.22
Week 41	Oct Wk 2	T max	31.12	33.23	32.90	33.00	30.17	33.02	33.13	33.33
		T min	20.65	20.74	20.40	20.87	20.73	20.80	21.96	21.56
		Rainfall	14.67	17.05	22.84	22.03	18.95	15.36	15.49	13.73
Week 42	Oct Wk 3	T max	31.44	33.35	32.96	32.95	30.11	32.89	32.88	33.14
		T min	19.42	19.29	19.08	19.49	19.33	19.37	20.77	20.26
		Rainfall	6.11	6.88	9.81	10.71	20.89	8.04	12.56	11.58
Week 43	Oct Wk 4	T max	31.42	32.83	32.52	32.52	29.76	32.24	32.13	32.51
		T min	17.95	17.87	17.85	18.11	18.00	18.08	19.49	19.04
		Rainfall	3.36	4.69	4.90	3.99	8.89	6.82	7.19	6.67
		Total Rainfall	38.29	44.12	57.07	60.42	75.89	48.47	58.25	55.2

Figures in Orange indicate deficit rainfall, in Brown indicate higher temperatures and in Green indicate lower temperatures as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 28-32 °C	Tmax: 31-33 °C	Tmax: 31-32 °C	Tmax: 30-34 °C
Tmin: 20-23 °C	Tmin: 15-17 °C	Tmin: 14-18 °C	Tmin: 15-23 °C
Rainfall: 380 mm	Rainfall: 2 mm	Rainfall: 3 mm	Rainfall: 2-50 mm

Figures in Orange indicate deficit rainfall, in Brown indicate higher temperatures and in Green indicate lower temperatures as compared to the optimal scenario

The projected maximum temperatures during the boll setting period fall slightly outside the optimal range in Khandesh and Vidarbha regions, and are within optimal range in Marathwada. In all three regions, minimum temperatures fall below the optimal range, and in Khandesh and Marathwada are completely outside the range for optimal growth. Rainfall is negligible compared to the required amount, and this is highly concerning for yields.

District wise Future Climate Data (2021-2050)

Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 40	Oct Wk 1	T max	32.89	31.67	31.97	31.78	31.40	33.30
		T min	17.33	16.63	17.54	17.68	17.50	22.77
		Rainfall	0.42	1.26	1.22	0.98	0.62	21.83
Week 41	Oct Wk 2	T max	32.28	31.17	31.46	31.07	30.84	33.67
		T min	16.09	15.50	16.46	16.49	16.34	22.10
		Rainfall	0.90	1.25	1.82	0.80	0.79	12.98
Week 42	Oct Wk 3	T max	31.80	30.81	31.09	30.55	30.47	33.56
		T min	15.31	14.81	15.74	15.64	15.55	21.31
		Rainfall	0.34	0.61	0.35	0.76	0.13	8.68
Week 43	Oct Wk 4	T max	31.45	30.52	30.80	30.18	30.16	33.22
		T min	14.71	14.23	15.11	15.00	14.86	20.50
		Rainfall	0.03	0.11	0.07	0.31	0.14	6.64
		Total Rainfall	1.69	3.23	3.46	2.85	1.68	50.13

Figures in Orange indicate deficit rainfall, in Brown indicate higher temperatures and in Green indicate lower temperatures as compared to the optimal scenario

Farmer Observations

- Rain enters partially open bolls and destroys the cotton fibers inside.
- High rainfall causes fungal diseases and rotting of the bolls.
- The cumulative impact of all of this is yield loss.

Inference

The main climatic challenge in the past has been heavy rain during October destroying the harvest. While the crop requires a lot of water at this time, it is mild and continuous rain that is needed, not high intensity rain. High intensity rain causes damage to the developing bolls and causes loss in yield. The future projection involves a lot less rainfall and drought conditions during boll setting. This is concerning as boll setting is a time when the carbohydrates and proteins synthesized accumulate in the bolls, and having adequate water and sunshine is essential for the filling of bolls. Lack of water will impact yields, and the extremely low amounts of precipitation will likely necessitate irrigation.

Stage 5

Boll Bursting
November - December

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 30-39 °C	Tmax: 30-32 °C	Tmax: 30-32 °C	Tmax: 30-32 °C
Tmin: 8-17 °C	Tmin: 14-17 °C	Tmin: 14-17 °C	Tmin: 14-19 °C
Rainfall: 66 mm	Rainfall: 14-19 mm	Rainfall: 15-25 mm	Rainfall: 11-17 mm

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario

Maximum and minimum temperatures are within the optimal range for the stage of boll bursting with the exception of the minimum temperature in Yavatmal and Chandrapur districts in the first week of November which is higher than optimal. Rainfall is lower than the optimal range in all three regions.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 44	Nov Wk 1	T max	31.32	32.29	32.02	31.93	29.67	31.61	31.63	31.96
		T min	17.12	16.92	16.86	17.01	17.21	17.16	18.52	18.09
		Rainfall	1.82	1.80	2.97	2.77	4.16	2.26	3.27	1.98
Week 45	Nov Wk 2	T max	31.47	32.26	31.97	31.99	30.02	31.61	31.72	32.04
		T min	17.13	16.57	16.33	16.37	16.62	16.60	17.53	17.33
		Rainfall	0.30	1.23	1.82	1.36	1.25	1.75	1.37	2.37
Week 46	Nov Wk 3	T max	30.97	31.43	31.25	31.25	29.66	30.77	31.11	31.35
		T min	16.82	16.30	16.10	16.19	16.62	16.23	17.14	17.00
		Rainfall	7.21	7.90	9.88	8.03	3.45	5.38	2.13	3.40
Week 47	Nov Wk 4	T max	31.06	30.86	30.88	30.82	29.75	30.21	30.48	30.83
		T min	15.87	15.47	15.53	15.57	15.76	15.42	16.36	16.28
		Rainfall	2.14	2.89	4.25	2.97	3.55	2.28	2.62	3.20
Week 48	Nov Wk 5	T max	31.06	30.84	30.97	30.88	30.01	30.15	30.32	30.82
		T min	15.40	14.71	14.72	14.70	15.17	14.70	15.42	15.51
		Rainfall	0.88	2.48	3.10	1.59	0.85	3.29	0.29	0.58
Week 49	Dec Wk 1	T max	30.83	30.21	30.45	30.31	29.76	29.54	29.75	30.25
		T min	14.70	14.04	13.83	13.93	14.37	13.83	14.49	14.64
		Rainfall	2.00	2.95	2.54	2.46	1.52	1.61	1.03	1.01
		Total Rainfall	14.35	19.25	24.56	19.18	14.78	16.57	10.71	12.54

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth: Tmax: 30-39 °C Tmin: 8-17 °C Rainfall: 66 mm	**Khandesh** Tmax: 31-32 °C Tmin: 14-15 °C Rainfall: 1 mm	**Marathwada** Tmax: 30-32 °C Tmin: 13-16 °C Rainfall: 1 mm	**Vidarbha** Tmax: 30-33 °C Tmin: 14-20 °C Rainfall: 2-7 mm

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario.

In the future, temperatures are predicted to be within the range for optimal growth, with the exception of the minimum temperature of Yavatmal in the first week of November. Rainfall is very low as compared to the optimal amount.

District wise Future Climate Data (2021-2050)

Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 44	Nov Wk 1	T max	31.21	30.35	30.61	29.82	29.87	32.76
		T min	14.30	13.82	14.83	14.71	14.50	19.54
		Rainfall	0.16	0.12	0.19	0.36	0.14	3.60
Week 45	Nov Wk 2	T max	31.01	30.19	30.50	29.56	29.69	32.30
		T min	13.91	13.42	14.61	14.49	14.30	18.75
		Rainfall	0.56	0.29	0.27	0.43	0.53	1.37
Week 46	Nov Wk 3	T max	30.98	30.18	30.52	29.50	29.73	31.63
		T min	14.16	13.65	14.92	14.82	14.72	17.85
		Rainfall	0.35	0.27	0.23	1.05	0.93	0.97
Week 47	Nov Wk 4	T max	31.40	30.61	30.96	29.90	30.07	31.09
		T min	14.61	14.14	15.37	15.06	15.20	16.80
		Rainfall	0.11	0.11	0.28	0.58	0.28	1.07
Week 48	Nov Wk 5	T max	31.60	30.85	31.25	30.11	30.33	30.61
		T min	14.58	14.10	15.46	15.18	15.59	15.85
		Rainfall	0.01	0.07	0.14	0.14	0.26	0.29
Week 49	Dec Wk 1	T max	31.99	31.27	31.75	30.51	30.71	30.33
		T min	14.52	14.05	15.53	15.29	15.95	15.08
		Rainfall	0.01	0.02	0.06	0.14	0.25	0.16
		Total Rainfall	1.2	0.88	1.17	2.7	2.39	7.46

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperature as compared to the optimal scenario.

Farmer Observations

- Farmers have mentioned that rainfall (in recent years) at this time is highly detrimental to yield for the same reasons as in the previous stage: destruction of lint in open bolls and increased incidences of fungal diseases.
- Increased moisture in cotton lint results in lower price of the cotton produce.

Inference

November is the time of the first picking of cotton, and rainfall at this time is highly detrimental, as a greater percentage of bolls have burst open. The open balls are easily destroyed by small amounts of rainfall, especially if there is no strong sunlight to dry them out afterwards. By this point, many bolls are revealed have been affected by the pink and American boll worms, which cause further reduction to the yield. Harvesting is delicate, labour performed over long hours by women, and there is often a shortage of labour. The second picking is done when the farmer judges the trade-off between labour prices, proportion of bolls opened and amount of good quality cotton that can be obtained to be in their favour. If it rains during the time of picking, or between pickings, yield is further lost. In the future projection, rainfall from September onward falls to almost none, and possibly the loss of yield due to heavy rainfall at the mature stage will be greatly reduced. However, cotton has multiple pickings, and only the earliest set boll reach maturity during November. Bolls that are set towards the end of October are still maturing during the November picking, and still need water for their development. The negligible rain during the time harvest will negatively affect the bolls from the next pickings. Temperature averages in the historical and future period remain roughly within optimal range, and perhaps several problems from this stage will be alleviated, but at the cost of very low soil moisture.

3.2.2 Summary and Discussion

A summary of the climate risks found through climate analyses and farmer validation is given below:

Summary of Climate Effects

Stage 1: Sowing and Vegetative Growth	Stage 2: Square Formation	Stage 3: Flowering	Stage 4: Boll Setting	Stage 5: Boll Bursting
*Week: 23,24,25,26,27,28 Jun weeks: 1,2,3,4 Jul weeks: 1,2	*Week: 29,30,31,32,33,34,35 Jul weeks: 3,4 Aug weeks: 1,2,3,4,5	*Week: 36,37,38,39 Sep weeks: 1,2,3,4	*Week: 40,41,42,43 Oct weeks: 1,2,3,4	*Week: 44,45,46,47,48,49 Nov weeks: 1,2,3,4,5 Dec weeks: 1
				
PRESENT CLIMATE RISKS				
High temperatures Late onset of monsoon Excess rainfall	High temperatures Excess rainfall High Humidity	Erratic Rainfall Strong winds High temperatures	Excess rainfall	Harvest destruction by rainfall
IMPACTS				
Germination loss Pests and fungal diseases	Squares dropped Pests and fungal diseases promoted Plant death from water stress	Water logging, root rot and fungal diseases Plants fall over Flowers dropped	Yield loss due to boll rot and fiber degradation from rain	Yield loss Profit reduction
ADAPTATIONS				
Double sowing Increased spraying of pesticide and herbicides	Increased pesticide spraying	Increased spraying		
FUTURE CLIMATE RISKS				
High temperatures Excess rainfall	High temperatures Excess rainfall	High temperatures Inadequate rainfall	Inadequate rainfall	Inadequate rainfall

** Denotes week of the year*

Discussion

Rainfall makes up the largest share of the climatic challenges currently face by cotton. Large amounts of intense rainfall have caused a lot of damage to cotton plants. Soil degradation has led to a reduction in their moisture holding capacity, and intense bursts of rainfall exceed the soil water capacity and create a water logged environment for crops. In such conditions, roots are starved of oxygen, and parts of the plant that would not have otherwise been exposed to standing water, like the stem and leaves, fall victim to fungal diseases that are promoted in damp conditions.

All these factors create stress in the plant, and as farmers have observed, plants can die from this shock. Most of the water eventually runs off and is not held by the soil, and if a dry spell follows intense rainfall, the plants can as easily be stressed from a lack of water. Building soil structure is crucial for cotton, as an excess of rainfall precedes a deficit. In the future prediction, rainfall will further concentrate in the months of July and August, with very a large excess of rainfall during these months and then an extreme deficit from September onward. If soils can hold more water, the adverse effects of these extremes on the cotton crop can be moderated.

Rainwater harvesting systems, and micro-irrigation facilities may also make a significant difference to the water related challenges in the future. Additionally, cotton soils are often high in calcium carbonate, and low in essential nutrients like Nitrogen, Manganese, Boron, Magnesium, Copper, and Sulphur, and these nutrient imbalances cause deficiency diseases as well as reduced resistance to pests due to improper nutrition.

Rainfall and temperature combine here in the case of cotton to create humid conditions that promote pests. Cotton has 24 pest species that affect it, and humid conditions create the perfect environment for various species to thrive. Mealy bugs, Spodoptera, thrips, whitefly are all predicted to increase with climate change. Bt cotton, developed to prevent attacks of the American bollworm on cotton, has been widely adopted in Maharashtra and is associated with increased inputs to obtain high yields.

At this point, the American bollworm is resistant to Bt toxins produced by the plant, and in the stressed conditions that cotton grows under in Maharashtra, it too attacks Bt cotton plants. While Bt Cotton was introduced to reduce the pesticide use associated with cotton, presently comparable amounts of pesticide to non Bt cotton are sprayed on Bt cotton as well. Spreading Integrated Pest Management packages to cotton farmers is essential.

Cotton is a plant that is sensitive to high temperatures. For some cotton cultivars studied, fiber fineness and quality declined from temperatures 32 °C onward. Khandesh and Vidarbha cross this threshold in the temperatures predicted for the period of boll setting. High temperatures during the reproductive period have been found to reduce pollen viability, cotton sterility and issues with boll retention. High temperatures are also predicted to change the timings of stages, with a shorter vegetative phase and a longer reproductive phase.

While this may seem beneficial, the vegetative growth is not sufficient to support the longer reproductive period, and boll formation may cease early as there are not enough resources to support development of both existing bolls and new squares. Breeding cultivars with increased heat tolerance is key to successfully grow cotton in the coming years.

3.3 Wheat

Wheat is a long period Rabi crop, planted in November and harvested in March. It is grown under irrigated conditions in Maharashtra. The analysis and findings for each stage and overall cropping cycle are given below.

3.3.1 Stagewise Analysis

A summary of the stages of wheat is provided below:

Wheat Crop Calendar

Stage 1: Sowing and Emergence	Stage 2: Tillering and Stem Elongation	Stage 3: Booting, Heading and Anthesis	Stage 4: Grain Filling	Stage 5: Maturity
				
*Week: 46,47,48 Nov weeks: 3,4,5/	*Week: 49,50,51,52,1,2 Dec weeks: 1,2,3,4 Jan weeks: 1,2	*Week: 3,4,5 Jan weeks: 3,4 Feb weeks: 1	*Week: 6,7,8,9,10 Feb weeks: 2,3,4 March weeks: 1,2	*Week: 11,12,13 March weeks: 3,4,5
Seeds are planted by tractor or seed drill Young plants emerge from the ground Crown of the plant and root are initiated	Tillers, or additional stems develop from the main stem Stems of a plant elongate and nodes and leaves become visible Flag leaf (last leaf or uppermost leaf) becomes visible	Booting: The head is developed within the sheath of the flag leaf Heading: The head emerges from the sheath Anthesis: The head flowers	The kernels of grain in the head develop. The grain goes from watery and soft to hard and dry	Kernels are ripe for harvest Leaves and stems of the wheat plant are dead and dry

** Denotes week of the year*

Stage 1

Sowing and Emergence
November

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 27-36 °C	Tmax: 31 °C	Tmax: 30-31 °C	Tmax: 30-31 °C
Tmin: 10-19 °C	Tmin: 15-17 °C	Tmin: 15-17 °C	Tmin: 15-17 °C
Rainfall: 38 mm	Rainfall: 10-13 mm	Rainfall: 8-17 mm	Rainfall: 5-11 mm

Figures in Orange indicate deficit rainfall as compared to the optimal scenario

During sowing and emergence, maximum and minimum temperatures remain well within the optimal range. Rainfall is less than required, but all wheat is irrigated, and hence low rainfall is not a limiting factor for the farmers growing wheat.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 46	Nov Wk 3	T max	30.97	31.43	31.25	31.25	29.66	30.77	31.11	31.35
		T min	16.82	16.30	16.10	16.19	16.62	16.23	17.14	17.00
		Rainfall	7.21	7.90	9.88	8.03	3.45	5.38	2.13	3.40
Week 47	Nov Wk4	T max	31.06	30.86	30.88	30.82	29.75	30.21	30.48	30.83
		T min	15.87	15.47	15.53	15.57	15.76	15.42	16.36	16.28
		Rainfall	2.14	2.89	4.25	2.97	3.55	2.28	2.62	3.20
Week 48	Nov Wk 5	T max	31.06	30.84	30.97	30.88	30.01	30.15	30.32	30.82
		T min	15.40	14.71	14.72	14.70	15.17	14.70	15.42	15.51
		Rainfall	0.88	2.48	3.10	1.59	0.85	3.29	0.29	0.58
		Total Rainfall	10.23	13.27	17.23	12.59	7.85	10.95	5.04	7.18

Figures in Orange indicate deficit rainfall as compared to the optimal scenario

Future Climate Summary (2021-2050)

Climate for optimal growth:	Khandesh	Marathwada	Vidarbha
Tmax: 27-36 °C	Tmax: 31-32 °C	Tmax: 30-31 °C	Tmax: 30-32 °C
Tmin: 10-19 °C	Tmin: 14-15 °C	Tmin: 14-15 °C	Tmin: 15-18 °C
Rainfall: 38 mm	Rainfall: 0 mm	Rainfall: 0-1 mm	Rainfall: 1-2 mm

Figures in Orange indicate deficit rainfall as compared to the optimal scenario

In the future scenario, maximum and minimum temperatures remain within range. Rainfall drops to even lower amounts, with almost no rainfall over these weeks. This may require more irrigation input than present.

District wise Future Climate Data (2021-2050)

Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 46	Nov Wk 3	T max	30.98	30.18	30.52	29.50	29.73	31.63
		T min	14.16	13.65	14.92	14.82	14.72	17.85
		Rainfall	0.35	0.27	0.23	1.05	0.93	0.97
Week 47	Nov Wk 4	T max	31.40	30.61	30.96	29.90	30.07	31.09
		T min	14.61	14.14	15.37	15.06	15.20	16.80
		Rainfall	0.11	0.11	0.28	0.58	0.28	1.07
Week 48	Nov Wk 5	T max	31.60	30.85	31.25	30.11	30.33	30.61
		T min	14.58	14.10	15.46	15.18	15.59	15.85
		Rainfall	0.01	0.07	0.14	0.14	0.26	0.29
		Total Rainfall	0.47	0.45	0.65	1.77	1.47	2.33

Figures in Orange indicate deficit rainfall as compared to the optimal scenario

Farmer Observations

- At the time of sowing, the ground needs adequate soil moisture, which used to be present from the end of the monsoon rain, but now the ground is not wet enough.
- A traditional indicator of the right time to sow was when temperatures became low enough for coconut oil to solidify. Now farmers obtain the best yield if they sow closer to the 1st of November.

Inference

This first stage of wheat is not heavily affected by climate events, as timely sowing is not dependent on the monsoon, and frequent irrigations are provided to meet the needs of the crop. Increasing amounts of irrigation water will be required in the future as soil moisture before sowing will drop further.

Stage 2

Tillering and Stem Elongation
December - January

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 22-34 °C	Tmax: 29-31 °C	Tmax: 29-30 °C	Tmax: 28-30 °C
Tmin: 7-18 °C	Tmin: 12-15 °C	Tmin: 12-14 °C	Tmin: 12-15 °C
Rainfall: 220 mm	Rainfall: 6-9 mm	Rainfall: 6-7 mm	Rainfall: 7-11 mm

Figures in Orange indicate deficit rainfall as compared to the optimal scenario.

Maximum and minimum temperatures during the stage of tillering and stem elongation remain within the range required for optimal growth. Rainfall is inadequate, and the crop needs irrigation to fill the gap due to deficit rainfall.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 49	Dec Wk 1	T max	30.83	30.21	30.45	30.31	29.76	29.54	29.75	30.25
		T min	14.70	14.04	13.83	13.93	14.37	13.83	14.49	14.64
		Rainfall	2.00	2.95	2.54	2.46	1.52	1.61	1.03	1.01
Week 50	Dec Wk 2	T. max	30.58	29.79	30.04	30.00	29.71	29.12	29.44	29.92
		T min	13.72	12.81	12.79	12.88	13.36	12.91	13.68	13.71
		Rainfall	1.58	2.41	2.15	1.95	0.58	1.16	1.26	0.85
Week 51	Dec Wk 3	T max	30.46	29.40	29.76	29.65	29.82	28.60	28.95	29.49
		T min	13.36	12.31	12.29	12.32	13.43	12.26	13.02	13.14
		Rainfall	0.76	0.82	0.30	0.68	0.44	0.78	1.24	0.51
Week 52	Dec Wk 4	T max	30.21	29.06	29.51	29.41	29.69	28.36	28.74	29.29
		T min	13.21	12.25	12.21	12.27	13.23	12.14	12.90	13.03
		Rainfall	0.17	0.19	0.29	0.41	0.55	0.87	2.36	0.72
Week 1	Jan Wk 1	T max	29.93	28.63	29.11	29.18	29.91	27.85	28.52	29.05
		T min	12.99	12.44	12.54	12.69	13.47	12.41	13.29	13.48
		Rainfall	0.70	1.80	1.24	1.58	1.85	3.69	3.23	1.94
Week 2	Jan Wk 2	T max	30.32	29.02	29.53	29.56	30.38	28.20	28.64	29.37
		T min	12.83	12.25	12.43	12.74	13.50	12.46	13.36	13.51
		Rainfall	0.54	0.46	0.71	0.37	0.70	0.85	2.00	1.50
		Total Rainfall	5.75	8.63	7.23	7.45	5.64	8.96	11.12	6.53

Figures in Orange indicate deficit rainfall as compared to the optimal scenario.

Future Climate Summary (2021-2050)			
Climate for optimal growth: Tmax: 22-34 °C Tmin: 7-18 °C Rainfall: 220 mm	**Khandesh** Tmax: 32-36 °C Tmin: 15-18 °C Rainfall: 0 mm	**Marathwada** Tmax: 31-36 °C Tmin: 14-19 °C Rainfall: 0 mm	**Vidarbha** Tmax: 30-35 °C Tmin: 15-20 °C Rainfall: 2-4 mm

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario.

In the future climate prediction, predicted maximum temperatures exceed the range for optimal growth. Towards the end of this stage, in mid-January, even minimum temperatures exceed the optimal range. This is a challenge as wheat requires cold temperatures for proper growth. Jalna and Jalgaon both reach 36 degrees in mid-Jan which could be detrimental to the growth and development of the crop.

District wise Future Climate Data (2021-2050)

Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 49	Dec Wk 1	T max	31.99	31.27	31.75	30.51	30.71	30.33
		T min	14.52	14.05	15.53	15.29	15.95	15.08
		Rainfall	0.01	0.02	0.06	0.14	0.25	0.16
Week 50	Dec Wk 2	T max	32.50	31.78	32.40	31.13	31.41	30.08
		T min	14.74	14.28	15.79	15.69	16.47	14.86
		Rainfall	0.02	0.03	0.08	0.33	0.46	0.17
Week 51	Dec Wk 3	T max	32.94	32.27	33.04	31.80	32.17	29.87
		T min	14.83	14.40	16.01	15.99	16.98	14.72
		Rainfall	0.01	0.01	0.01	0.44	0.32	0.40
Week 51	Dec Wk 4	T max	33.85	33.13	33.93	32.84	33.15	29.94
		T min	15.57	15.10	16.81	16.82	17.80	15.12
		Rainfall	0.00	0.00	0.00	0.46	0.37	0.87
Week 1	Jan Wk 1	T max	34.87	34.05	34.79	33.87	34.25	30.39
		T min	16.86	16.38	18.10	18.02	18.77	15.65
		Rainfall	0.00	0.00	0.07	0.84	0.72	0.49
Week 2	Jan Wk 2	T max	35.82	34.98	35.65	34.77	35.19	30.69
		T min	18.02	17.50	19.17	18.94	19.63	15.82
		Rainfall	0.00	0.00	0.16	1.23	1.42	0.35
		Total Rainfall	0.04	0.06	0.38	3.44	3.54	2.44

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario.

Farmer Observations

- Crops require around 100 days of cold temperatures after the seedling stage for good growth and yield. This is no longer possible as it does not get cold enough.
- When it is cold enough, the cold suppresses weeds and pests to some extent, and few, if any, herbicides and pesticides are required.
- Cold temperatures are essential for crop development, and yields are reducing over the years as it grows warmer.

Inference

The future projection for maximum and minimum temperatures show that both begin to exceed optimal ranges, which was not the case historically. As wheat is a cold season crop, a warming of temperature has a negative effect not only on weed, pest and disease incidence, but also on crop physiology.

Stage 3

Flowering
January - February

Historical Climate Summary (1989-2018)			
Climate for optimal growth: Tmax: 22-34 °C Tmin: 5-17 °C Rainfall: 171 mm	**Khandesh** Tmax: 30-33 °C Tmin: 13-15 °C Rainfall: 1 mm	**Marathwada** Tmax: 30-33 °C Tmin: 13-16 °C Rainfall: 1-5 mm	**Vidarbha** Tmax: 29-31 °C Tmin: 13-15 °C Rainfall: 3-7 mm
Figures in Orange indicate deficit rainfall as compared to the optimal scenario			

Interestingly, while temperatures were higher than optimum towards the end of the vegetative period, during the flowering period they dip back down into the range of optimal temperatures, and remain slightly below. Rainfall is very low, and irrigation must take place before anthesis to ensure adequate soil moisture.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 3	Jan Wk 3	T max	31.11	29.86	30.30	30.35	31.37	29.09	29.43	30.21
		T min	13.19	12.66	12.70	13.20	13.89	12.91	13.67	13.91
		Rainfall	0.15	0.41	0.44	0.33	2.06	0.86	1.15	1.19
Week 4	Jan Wk 4	T max	31.66	30.15	30.74	30.79	32.04	29.37	29.85	30.60
		T min	13.78	12.81	13.06	13.53	14.56	13.16	14.27	14.36
		Rainfall	0.50	0.58	0.45	0.27	0.95	0.93	3.61	1.55
Week 5	Feb Wk 1	T max	32.54	30.89	31.56	31.46	32.89	30.19	30.53	31.32
		T min	14.54	13.53	13.78	14.09	15.50	13.83	14.88	14.90
		Rainfall	0.13	0.23	0.27	0.32	1.77	1.56	2.64	3.45
		Total Rainfall	0.78	1.22	1.16	0.92	4.78	3.35	7.4	6.19

Figures in Orange indicate deficit rainfall as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth: Tmax: 22-34 °C Tmin: 5-17 °C Rainfall: 171 mm	**Khandesh** Tmax: 37-39 °C Tmin: 19-21 °C Rainfall: 0 mm	**Marathwada** Tmax: 36-38 °C Tmin: 19-22 °C Rainfall: 0-1 mm	**Vidarbha** Tmax: 31-38 °C Tmin: 16-22 °C Rainfall: 1-7 mm
Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario.			

During the booting, heading and anthesis stage, projected maximum and minimum temperatures are higher than the optimal range. In fact, future temperatures are outside optimal growth parameters for all weeks in all districts except Yavatmal. This is a major climate risk. Rainfall is very low to almost none, and the need for irrigation will continue.

District wise Future Climate Data (2021-2050)								
Week of the Year	**Month & Week**	**Variable**	**Khandesh**	**Marathwada**		**Vidarbha**		
			Jalgaon	**Aurangabad**	**Jalna**	**Amravati**	**Chandrapur**	**Yavatmal**
Week 3	Jan Wk 3	T max	36.94	36.01	36.71	35.9	36.3	31.18
		T min	19.32	18.68	20.3	20.15	20.85	16.18
		Rainfall	0.03	0.01	0.21	1.36	2.09	0.36
Week 4	Jan Wk 4	T max	37.9	36.9	37.73	37.11	37.49	31.81
		T min	19.91	19.19	20.91	20.91	21.67	16.56
		Rainfall	0.03	0.03	0.22	1.27	2.17	0.5
Week 5	Feb Wk 1	T max	38.64	37.53	38.42	38.06	38.37	32.64
		T min	20.57	19.82	21.57	21.71	22.44	17.01
		Rainfall	0	0.04	0.35	1.58	2.28	0.21
		Total Rainfall	0.06	0.08	0.78	4.21	6.54	1.07

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario.

Farmer Observations

- If there is rainfall at this time, it adds to the irrigation already provided and causes damage to the plant. Farmers mentioned the need to ensure there was no excess of water at this stage.
- Sometimes pesticide spraying is required at this time.

Inference

Booting, heading and anthesis are very important in determining yield as this is when the head which will eventually bear grain develops, emerges and flowers. Higher than optimal temperatures at this time will cause damage to plant structures, especially sensitive reproductive ones. While farmers have reported incidences of too much soil moisture during this time from rainfall (in the past few years), in the future, the opposite problem of a lack of soil moisture will prevail.

Stage 4

Grain Filling
February - March

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 20-36 °C	Tmax: 32-36 °C	Tmax: 32-37 °C	Tmax: 31-35 °C
Tmin: 5-19 °C	Tmin: 14-18 °C	Tmin: 14-19 °C	Tmin: 15-19 °C
Rainfall: 132 mm	Rainfall: 3-7 mm	Rainfall: 6-10 mm	Rainfall: 12-15 mm

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario.

Minimum and maximum temperatures historically have remained roughly within the optimal range. Rainfall is much lower than optimal, and irrigation is required to meet the water requirement of the crop.

District wise Historical Climate Data (1989-2018)										
Week of the Year	**Month & Week**	**Variable**	**Khandesh**		**Marathwada**			**Vidarbha**		
			Dhule	**Jalgaon**	**Aurangabad**	**Jalna**	**Nanded**	**Amravati**	**Chandrapur**	**Yavatmal**
Week 6	Feb Wk 2	T max	33.00	31.59	32.05	32.10	33.57	30.93	31.45	32.09
		T min	14.94	14.37	14.45	14.93	16.38	14.81	16.02	16.02
		Rainfall	0.44	0.64	0.46	0.29	0.65	0.83	2.29	1.06
Week 7	Feb Wk 3	T max	33.40	32.21	32.80	32.71	34.46	31.52	32.10	32.72
		T min	15.43	15.00	15.14	15.54	16.87	15.34	16.62	16.57
		Rainfall	0.80	1.17	0.55	0.34	1.08	1.65	2.57	1.89
Week 8	Feb Wk 4	T max	34.66	33.40	33.94	33.75	35.39	32.78	33.19	33.78
		T min	16.16	15.58	15.63	16.03	17.23	15.88	17.13	17.04
		Rainfall	0.02	0.11	0.10	0.46	0.69	1.14	1.31	0.82
Week 9	Mar Wk 1	T max	35.81	34.57	35.01	34.93	36.56	34.10	34.53	35.11
		T min	17.53	17.03	16.90	17.36	18.61	17.30	18.30	18.30
		Rainfall	0.83	2.23	1.36	1.57	2.56	4.51	3.09	2.56
Week 10	Mar Wk 2	T max	35.99	34.80	35.20	35.12	36.77	34.30	34.72	35.30
		T min	17.46	17.41	17.29	17.85	19.21	17.66	18.99	18.85
		Rainfall	0.89	2.84	3.65	4.39	5.31	5.27	6.08	5.62
		Total Rainfall	2.98	6.99	6.12	7.05	10.29	13.4	15.34	11.95

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario.

Future Climate Summary (2021-2050)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 20-36 °C	Tmax: 39-42 °C	Tmax: 38-42 °C	Tmax: 34-42 °C
Tmin: 5-19 °C	Tmin: 21-26 °C	Tmin: 20-26 °C	Tmin: 18-27 °C
Rainfall: 132 mm	Rainfall: 0 mm	Rainfall: 0-1 mm	Rainfall: 3-10 mm

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario.

Projected temperatures rise even higher, and reach a maximum of 42 °C in all three regions, with the exception of Yavatmal district. This can have a serious impact on yield if adaptations are not found. Rainfall is negligible and would warrant additional irrigation.

District wise Future Climate Data (2021-2050)								
Week of the Year	**Month & Week**	**Variable**	**Khandesh**	**Marathwada**		**Vidarbha**		
			Jalgaon	**Aurangabad**	**Jalna**	**Amravati**	**Chandrapur**	**Yavatmal**
Week 6	Feb Wk 2	T max	39.36	38.18	39.13	38.88	39.23	33.62
		T min	21.23	20.48	22.32	22.49	23.30	17.80
		Rainfall	0.07	0.03	0.13	0.83	1.41	0.21
Week 7	Feb Wk 3	T max	40.17	38.89	39.82	39.79	40.11	34.46
		T min	22.26	21.34	23.19	23.52	24.43	18.84
		Rainfall	0.04	0.04	0.13	0.61	1.83	0.41
Week 8	Feb Wk 4	T max	40.82	39.45	40.32	40.50	40.78	35.32
		T min	23.45	22.31	24.03	24.52	25.38	19.75
		Rainfall	0.00	0.03	0.30	0.78	3.09	1.02
Week 9	Mar Wk 1	T max	41.59	40.16	40.96	41.23	41.43	36.36
		T min	24.56	23.26	24.76	25.41	26.12	20.87
		Rainfall	0.00	0.02	0.36	0.23	2.54	1.25
Week 10	Mar Wk 2	T max	42.35	40.90	41.75	42.08	42.26	37.49
		T min	25.73	24.29	25.59	26.45	26.98	21.58
		Rainfall	0.00	0.05	0.28	0.10	1.48	1.30
		Total Rainfall	0.06	0.08	0.78	4.21	6.54	1.07

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario.

Farmer Observations

- Grains do not develop the expected amount, and swell less in higher temperatures.
- At this stage, the wheat has grown quite tall, and strong winds can cause damage to the stalks and fell the wheat so that it lies horizontally on the field.
- This time is known for prevailing strong winds, and a loss to yield is caused by these winds, as grains in contact with the soil spoil quickly and are exposed to many pests and diseases.
- This effect is felt more towards the edges of the planted area.
- Farmers prefer varieties that do not grow as tall, as these varieties have a reduced vulnerability to strong winds.
- Cloudy conditions lead to increased pest pressure, which impacts yield.

Inference

Farmers have already observed yield reducing with increasing temperatures in February and March. As these temperatures are projected to get much higher, there will certainly be a negative impact on the yield. Apart from the temperature and rainfall, other climatic patterns such as the strong winds during these months are also affecting yield. Further study on how climate change will affect the patterns of such phenomena is required, as it will have an effect on wheat yields.

Stage 5

Maturity
March - April

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 30-39 °C	Tmax: 36-39 °C	Tmax: 36-40 °C	Tmax: 36-39 °C
Tmin: 10-22 °C	Tmin: 19-21 °C	Tmin: 19-22 °C	Tmin: 19-22 °C
Rainfall: 0 mm	Rainfall: 2-4 mm	Rainfall: 4-5 mm	Rainfall: 5-6 mm

Figures in Blue indicate higher rainfall as compared to the optimal scenario

Once the crop has reached maturity, it is less sensitive to temperature and has a higher range of temperatures conducive to optimal growth. Historical temperatures fall roughly within this range, and rainfall, while not zero, is still low, but the crop no longer requires water. The amount of rainfall is not significant enough to damage the crop.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 11	Mar Wk 3	T max	37.33	36.11	36.25	36.25	37.93	35.70	35.87	36.47
		T min	19.08	18.79	18.58	18.97	20.64	18.99	20.11	20.01
		Rainfall	1.23	2.98	2.47	2.81	2.35	3.23	2.42	2.89
Week 12	Mar Wk 4	T max	38.31	37.38	37.60	37.70	39.10	37.28	37.54	38.05
		T min	19.78	19.92	19.82	20.28	21.69	20.32	21.37	21.26
		Rainfall	0.05	0.33	0.58	1.31	0.92	1.29	1.17	1.26
Week 13	Mar Wk 5	T max	39.17	38.24	38.33	38.53	39.73	38.28	38.44	38.93
		T min	20.54	20.77	20.57	21.18	22.21	21.27	22.29	22.15
		Rainfall	0.52	0.69	0.61	0.32	1.61	0.53	2.36	1.41
		Total Rainfall	1.8	4	3.66	4.44	4.88	5.05	5.95	5.56

Figures in Blue indicate higher rainfall as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 30-39 °C	Tmax: 43 °C	Tmax: 41-42 °C	Tmax: 38-44 °C
Tmin: 10-22 °C	Tmin: 26-27 °C	Tmin: 25-27 °C	Tmin: 22-29 °C
Rainfall: 0 mm	Rainfall: 1 mm	Rainfall: 2 mm	Rainfall: 2-5 mm

Figures in Brown indicate higher temperatures and in Blue indicate excess rainfall as compared to the optimal scenario

Despite the increase in the range of temperature mentioned above, projected temperatures are still higher than 39 °C, and reach 43 °C in Khandesh, and 44 °C in Chandrapur in Vidarbha. This is useful for grain to dry out, but may lead to strain in agricultural labourers during harvest time. There is an increase in rainfall in Amravati and Chandrapur districts which could be detrimental to the quality of wheat being harvested.

District wise Future Climate Data (2021-2050)								
Week of the Year	**Month & Week**	**Variable**	**Khandesh**	**Marathwada**		**Vidarbha**		
			Jalgaon	**Aurangabad**	**Jalna**	**Amravati**	**Chandrapur**	**Yavatmal**
Week 11	Mar Wk 3	T max	42.82	41.34	42.27	42.64	42.90	38.37
		T min	26.36	24.79	26.23	27.36	27.80	22.28
		Rainfall	0.06	0.12	0.24	0.19	1.67	1.46
Week 12	Mar Wk 4	T max	42.95	41.43	42.36	42.95	43.46	39.22
		T min	26.84	25.00	26.55	28.13	28.52	23.11
		Rainfall	0.70	1.27	0.84	0.42	1.68	0.93
Week 13	Mar Wk 5	T max	42.98	41.35	42.31	43.14	43.69	40.06
		T min	27.24	25.24	26.74	28.71	29.10	24.10
		Rainfall	0.29	0.88	1.01	1.05	1.76	0.99
		Total Rainfall	0.06	0.08	0.78	4.21	6.54	1.07

Figures in Blue indicate excess rainfall and in Brown indicate higher temperatures as compared to the optimal scenario

Farmer Observations

- Rain during the harvest weeks when grain was not yet harvested, but was mature, caused some loss to farmers.
- While grain was not destroyed, the rain caused a loss of polish in the grains, which led to a lower rate received when the harvest was sold.
- If it rained towards the end of March, after the grains had been harvested and has been laid out to dry in the sun, maximum damage was caused due to fungal diseases affecting the grain.

Inference

The main concern farmers had during the time of harvest was untimely rainfall, that lead to yield loss. In this sense, the rising temperatures and lessening rainfall trend observed may be beneficial, as grain will dry faster and the risk of untimely rain is lowered. However, these same conditions cause loss in earlier stages, and may in total cause more harm than good.

3.3.2 Summary and Discussion

A summary of the climate risks found through climate analyses and farmer validation is given below:

Summary of Climate Effects

Stage 1: Sowing and Emergence	Stage 2: Tillering and Stem Elongation	Stage 3: Booting, Heading and Anthesis	Stage 4: Grain Filling	Stage 5: Maturity
*Week: 46,47,48 Nov weeks: 3,4,5	*Week: 49,50,51,52,1,2 Dec weeks: 1,2,3,4 Jan weeks: 1,2	*Week: 3,4,5 Jan weeks: 3,4 Feb weeks: 1	*Week: 6,7,8,9,10 Feb weeks: 2,3,4 March weeks: 1,2	*Week: 11,12,13 March weeks: 3,4,5
				
PRESENT CLIMATE RISKS				
Low rainfall	Insufficient cold spell	High temperatures Heavy winds	Excess rainfall	Harvest destruction by rainfall
IMPACTS				
Difficulty in sowing	Impacted development of the crop		Low yield Yield loss from wind damage	Yield loss Profit reduction
ADAPTATIONS				
Irrigation			Using shorter height varieties	
FUTURE CLIMATE RISKS				
Low rainfall	High temperatures Negligible rainfall	High temperatures Negligible rainfall	High temperatures Negligible rainfall	High temperatures
** Denotes week of the year*				

Discussion

Wheat requires at least 5-6 irrigations for optimal growth, and it is not possible for a rainfed farmer to conventionally grow wheat. This means that the farmers growing wheat are a part of a small section of landholders with access to irrigation water and are able to adapt to water scarcity well. Unlike the Kharif cropping season, rainfall is not the primary form of climate challenges that wheat faces. With minimal inputs other than fertilizer, it is an inexpensive crop to grow in Maharashtra, and is a good choice for farmers in the Rabi season. Since fewer farmers plant during the Rabi season, there is lower competition for harvest labour and low pest and weed pressure. However, rising temperatures are the main challenge to wheat yields, and it is difficult to the farmer at an individual scale to find ways to adapt to this.

Many studies have been carried out to test the effect of rising temperatures on winter wheat. Temperatures over 25 °C during grain filling depress yields, and both historical and projected temperatures during grain filling are well over this. One study found a 5% grain yield loss for every 1 °C rise between 17.7 °C and 32.7 °C, affecting both grain growth rate and duration. Both day and night temperatures have an effect on wheat yield, and so increasing maximum and minimum temperatures pose a threat to yield. The carbohydrates stored in the grain are produced almost entirely by the flag leaf – a single topmost leaf on a stalk. Any stress to this leaf, such as water stress or heat stress, causing stomatal closure or wilting will have a marked effect on grain filling. Additionally, under heat stress situations, the usage of nitrogen changes in the plant, and impacts protein deposition in the grain. Since temperature cannot be controlled or supplemented by farmers, the main adaptation is the breeding of plants with higher heat tolerance.

Being a winter crop, wheat experiences the effects of ozone, which is higher in concentration over the environment during the winter months. An estimated 17% of wheat yield may be lost due to crop damage from ozone exposure.

The source of irrigation water for farmers is usually groundwater, and essentially all winter wheat contributes to usage of valuable groundwater resources. We also know that soil quality is linked to water percolation, and low fertility and eroded soils cannot hold water long enough for it to percolate. With projected rainfall in the winter months falling to almost zero, and soils already depleted of nutrients and organic matter, groundwater recharge will be doubly affected. The pressure of winter wheat on the water table in the already semi-arid regions of our study will be significant. Agriculture is not the only use of groundwater, and we need it urgently for drinking, domestic and ecological needs for our ever increasing population. Developing plans to manage groundwater and ensuring its recharge are crucial to ensure long term sustainability of groundwater resources.

From interactions with farmers, we see that the effects of heat on yield are clear to them, but heavy winds during grain filling and sudden rainfall during harvesting are connected more directly to yield loss. Rain during the harvest season is a cause of loss in the Kharif season as well, and adaptations to safely dry and store harvested crops become essential. Shorter height wheat varietals address the risk posed by strong winds. However, since future climate estimates predict increasing temperatures through the Rabi season, it is important to begin work on adaptations for upcoming yield loss due to increased heat, and increased weed, pest and disease pressure indirectly caused by the heat.

3.4 Gram

Gram is a long-duration Rabi crop, sown in October and harvested in February and is grown in irrigated condition in the state. The analysis and findings for each stage and overall cropping cycle is given below.

3.4.1 Stagewise Analysis

A summary of the stages of gram is provided below:

Gram Crop Calendar

Stage 1: Sowing and Emergence	Stage 2: Vegetative Growth	Stage 3: Flowering	Stage 4: Pod Formation and Filling	Stage 5: Maturity
				
*Week: 42,43 Oct weeks: 3,4	*Week: 44,45,46,47,48 Nov weeks: 1,2,3,4,5	*Week: 49,50 Dec weeks: 1,2	*Week: 51,52,1,2,3,4 Dec weeks: 3,4 Jan weeks: 1,2,3,4	*Week: 5,6,7 Feb weeks: 1,2,3
Seeds are planted along with fertilizer application New seedling emerges from the ground	Roots, stem and leaf of the plant further develop Plant grows in size	Buds appear and flowers bloom	Pods form from flowers Gram beans swell within the pod	Pods are fully developed and plant dries out Matured pods are harvested and further dried
** Denotes week of the year*				

Stage 1

Sowing and Emergence
October

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 28-34 °C	Tmax: 31-33 °C	Tmax: 30-33 °C	Tmax: 32-33 °C
Tmin: 17-20 °C	Tmin: 18-19 °C	Tmin: 18-19 °C	Tmin: 18-21 °C
Rainfall: 0 mm	Rainfall: 9-12 mm	Rainfall: 15-30 mm	Rainfall: 15-20 mm
Figures in Brown indicate higher temperatures and in Blue indicate excess rainfall as compared to the optimal scenario			

During sowing and emergence, maximum temperatures remain within the range for optimal growth, while minimum temperatures remain roughly within the range for optimal growth. Recommended rainfall is zero, assuming that there is sufficient residual moisture in the soil from the monsoon rain. The 10-30 mm excess rainfall is probably not detrimental as residual soil moisture at the time of Rabi planting is declining.

District wise Historical Climate Data (1989-2018)										
Week of the Year	**Month & Week**	**Variable**	**Khandesh**		**Marathwada**			**Vidarbha**		
			Dhule	**Jalgaon**	**Aurangabad**	**Jalna**	**Nanded**	**Amravati**	**Chandrapur**	**Yavatmal**
Week 42	Oct Wk 3	T max	31.44	33.35	32.96	32.95	30.11	32.89	32.88	33.14
		T min	19.42	19.29	19.08	19.49	19.33	19.37	20.77	20.26
		Rainfall	6.11	6.88	9.81	10.71	20.89	8.04	12.56	11.58
Week 43	Oct Wk4	T max	31.42	32.83	32.52	32.52	29.76	32.24	32.13	32.51
		T min	17.95	17.87	17.85	18.11	18.00	18.08	19.49	19.04
		Rainfall	3.36	4.69	4.90	3.99	8.89	6.82	7.19	6.67
		Total Rainfall	9.47	11.57	14.71	14.7	29.78	14.86	19.75	18.25

Figures in Brown indicate higher temperatures and in Blue indicate excess rainfall as compared to the optimal scenario.

Future Climate Summary (2021-2050)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 28-34 °C	Tmax: 31-32 °C	Tmax: 31 °C	Tmax: 30-34 °C
Tmin: 17-20 °C	Tmin: 15 °C	Tmin: 14-16 °C	Tmin: 15-21 °C
Rainfall: 0 mm	Rainfall: 0 mm	Rainfall: 0-1 mm	Rainfall: 0-15 mm

Figures in Brown indicate higher temperatures and in Blue indicate excess rainfall as compared to the optimal scenario.

Future projections for the weeks of sowing and planting of gram in October do not show any risks. Rainfall is close to zero with the exception of Yavatmal, and as with historical temperatures, maximums are within optimal range and minimums are roughly within optimal range.

District wise Future Climate Data (2021-2050)								
Week of the Year	**Month & Week**	**Variable**	**Khandesh**	**Marathwada**		**Vidarbha**		
			Jalgaon	**Aurangabad**	**Jalna**	**Amravati**	**Chandrapur**	**Yavatmal**
Week 42	Nov Wk 3	T max	31.80	30.81	31.09	30.55	30.47	33.56
		T min	15.31	14.81	15.74	15.64	15.55	21.31
		Rainfall	0.34	0.61	0.35	0.76	0.13	8.68
Week 43	Nov Wk 4	T max	31.45	30.52	30.80	30.18	30.16	33.22
		T min	14.71	14.23	15.11	15.00	14.86	20.50
		Rainfall	0.03	0.11	0.07	0.31	0.14	6.64
		Total Rainfall	0.37	0.72	0.42	1.07	0.27	15.32

Figures in Brown indicate higher temperatures and in Blue indicate excess rainfall as compared to the optimal scenario.

Farmer Observations

- The rule of thumb of planting adopted by the famers is when coconut oil solidifies no longer holds. It used to indicate an October 15th - 20th planting date, and now indicates an end-November planting date, as it grows cold enough later.
- Farmers must still plant in the third week of October for best yield, and there is around 10% seed germination loss due to less cold.
- If it rains a lot in September and October, there is high incidence of fungal diseases.

Inference

For the first stage of gram, temperatures are roughly within the range for optimal growth. Farmers note that at the time of planting it is not as cold as it used to be few years ago, and this is causing germination loss. While we did not see this in our historical and projected averages, if the trend continues, it may have an impact on the costs associated with gram due to purchase of more seed to make up for the loss in germination. Heavy rainfall in September and October have a detrimental effect on gram, but from future projection, there is likely to be low to no rainfall in these months. This will reduce fungal disease, but also reduce soil moisture, and may necessitate irrigation at this stage as well.

Stage 2

Vegetative Growth
November

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 24-32 °C	Tmax: 31-32 °C	Tmax: 30-32 °C	Tmax: 30-32 °C
Tmin: 10-18 °C	Tmin: 15-17 °C	Tmin: 15-17 °C	Tmin: 15-19 °C
Rainfall: 35-40 mm	Rainfall: 12-16 mm	Rainfall: 13-22 mm	Rainfall: 10-15 mm

Figures in Brown indicate higher temperatures and in Orange indicate deficit rainfall as compared to the optimal scenario.

Similar to the previous stage, temperatures during vegetative growth fall roughly within the optimal ranges. Rainfall here is about half of the required amount, one of the reasons gram has become a crop needing irrigation.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 44	Nov Wk 1	T max	31.32	32.29	32.02	31.93	29.67	31.61	31.63	31.96
		T min	17.12	16.92	16.86	17.01	17.21	17.16	18.52	18.09
		Rainfall	1.82	1.80	2.97	2.77	4.16	2.26	3.27	1.98
Week 45	Nov Wk 2	T. max	31.47	32.26	31.97	31.99	30.02	31.61	31.72	32.04
		T min	17.13	16.57	16.33	16.37	16.62	16.60	17.53	17.33
		Rainfall	0.30	1.23	1.82	1.36	1.25	1.75	1.37	2.37
Week 46	Nov Wk 3	T max	30.97	31.43	31.25	31.25	29.66	30.77	31.11	31.35
		T min	16.82	16.30	16.10	16.19	16.62	16.23	17.14	17.00
		Rainfall	7.21	7.90	9.88	8.03	3.45	5.38	2.13	3.40
Week 47	Nov Wk 4	T max	31.06	30.86	30.88	30.82	29.75	30.21	30.48	30.83
		T min	15.87	15.47	15.53	15.57	15.76	15.42	16.36	16.28
		Rainfall	2.14	2.89	4.25	2.97	3.55	2.28	2.62	3.20
Week 48	Nov Wk 5	T max	31.06	30.84	30.97	30.88	30.01	30.15	30.32	30.82
		T min	15.40	14.71	14.72	14.70	15.17	14.70	15.42	15.51
		Rainfall	0.88	2.48	3.10	1.59	0.85	3.29	0.29	0.58
		Total Rainfall	12.35	16.3	22.02	16.72	13.26	14.96	9.68	11.53

Figures in Brown indicate higher temperatures and in Orange indicate deficit rainfall as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth: Tmax: 24-32 °C Tmin: 10-18 °C Rainfall: 35-40 mm	**Khandesh** Tmax: 31-32 °C Tmin: 14-15 °C Rainfall: 1 mm	**Marathwada** Tmax: 30-31 °C Tmin: 13-15 °C Rainfall: 1 mm	**Vidarbha** Tmax: 30-33 °C Tmin: 14-20 °C Rainfall: 2-7 mm

Figures in Brown indicate higher temperatures and in Orange indicate deficit rainfall as compared to the optimal scenario

Other than the temperatures in Yavatmal district in the first week of November, temperatures remain completely within the range for optimal growth. Rainfall is projected to drop to almost none, necessitating use of more groundwater resources for increased irrigation.

District wise Future Climate Data (2021-2050)

Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 44	Nov Wk 1	T max	31.21	30.35	30.61	29.82	29.87	32.76
		T min	14.30	13.82	14.83	14.71	14.50	19.54
		Rainfall	0.16	0.12	0.19	0.36	0.14	3.60
Week 45	Nov Wk 2	T max	31.01	30.19	30.50	29.56	29.69	32.30
		T min	13.91	13.42	14.61	14.49	14.30	18.75
		Rainfall	0.56	0.29	0.27	0.43	0.53	1.37
Week 46	Nov Wk 3	T max	30.98	30.18	30.52	29.50	29.73	31.63
		T min	14.16	13.65	14.92	14.82	14.72	17.85
		Rainfall	0.35	0.27	0.23	1.05	0.93	0.97
Week 47	Nov Wk 4	T max	31.40	30.61	30.96	29.90	30.07	31.09
		T min	14.61	14.14	15.37	15.06	15.20	16.80
		Rainfall	0.11	0.11	0.28	0.58	0.28	1.07
Week 48	Nov Wk 5	T max	31.60	30.85	31.25	30.11	30.33	30.61
		T min	14.58	14.10	15.46	15.18	15.59	15.85
		Rainfall	0.01	0.07	0.14	0.14	0.26	0.29
		Total Rainfall	1.19	0.86	1.11	2.56	2.14	7.3

Figures in Brown indicate higher temperatures and in Orange indicate deficit rainfall as compared to the optimal scenario

Farmer Observations

- Cold weather at this time keeps diseases and pest away.
- In recent years, it has not been cold enough, and incidences of chickpea wilt has increased.

Inference

Since gram is irrigated, farmers do not mention a lack of rain as a risk, but rather focus on the effects of increasing temperature. While the averages show historical temperatures within optimal growth range and do not show an increase in the future, farmers have reported incidences of higher temperatures in recent years, leading to increased incidences of wilting. Adaptations to combat chickpea wilt and reducing water become necessary.

Stage 3

Flowering
December

Historical Climate Summary (1989-2018)			
Climate for optimal growth: Tmax: 30-35 °C Tmin: 17-18 °C Rainfall: 0-5 mm	**Khandesh** Tmax: 30-31 °C Tmin: 13-15 °C Rainfall: 4-5 mm	**Marathwada** Tmax: 30 °C Tmin: 13-14 °C Rainfall: 2-5 mm	**Vidarbha** Tmax: 29-30 °C Tmin: 13-15 °C Rainfall: 2-3 mm
Figures in Green indicate lower temperatures as compared to the optimal scenario			

Maximum temperatures are within range, however minimum temperatures are all below the optimal range. Rainfall is within the optimal range required during the flowering stage.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 49	Dec Wk 1	T max	30.83	30.21	30.45	30.31	29.76	29.54	29.75	30.25
		T min	14.70	14.04	13.83	13.93	14.37	13.83	14.49	14.64
		Rainfall	2.00	2.95	2.54	2.46	1.52	1.61	1.03	1.01
Week 50	Dec Wk 2	T max	30.58	29.79	30.04	30.00	29.71	29.12	29.44	29.92
		T min	13.72	12.81	12.79	12.88	13.36	12.91	13.68	13.71
		Rainfall	1.58	2.41	2.15	1.95	0.58	1.16	1.26	0.85
		Total Rainfall	3.58	5.36	4.69	4.41	2.1	2.77	2.29	1.86

Figures in Green indicate lower temperatures as compared to the optimal scenario

Future Climate Summary (2021-2050)			
Climate for optimal growth: Tmax: 30-35 °C Tmin: 17-18 °C Rainfall: 0-5 mm	**Khandesh** Tmax: 32 °C Tmin: 15 °C Rainfall: 0 mm	**Marathwada** Tmax: 31-32 °C Tmin: 14-16 °C Rainfall: 0 mm	**Vidarbha** Tmax: 30-31 °C Tmin: 15-16 °C Rainfall: 0-1 mm
Figures in Green indicate lower temperatures as compared to the optimal scenario			

Maximum temperatures are within range, however minimum temperatures are all below the optimal range required during flowering. Rainfall is within the optimal range required at this stage.

District wise Future Climate Data (2021-2050)								
Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 49	Dec Wk 1	T max	31.99	31.27	31.75	30.51	30.71	30.33
		T min	14.52	14.05	15.53	15.29	15.95	15.08
		Rainfall	0.01	0.02	0.06	0.14	0.25	0.16
Week 50	Dec Wk 2	T max	32.50	31.78	32.40	31.13	31.41	30.08
		T min	14.74	14.28	15.79	15.69	16.47	14.86
		Rainfall	0.02	0.03	0.08	0.33	0.46	0.17
		Total Rainfall	0.03	0.05	0.14	0.47	0.71	0.33

Figures in Green indicate lower temperatures as compared to the optimal scenario.

Farmer Observations

- Moisture becomes low in the soil and plant gets stressed.
- If temperatures get high in addition to low soil moisture, flowers drop.
- If it rains at this time, excess moisture may cause fungal disease.

Inference

Flowering is a very delicate stage that is sensitive to water stress. Additionally, soil moisture holding capacity has decreased over time. Excess moisture can easily lead to flooding and deficit can result in very low levels of soil moisture. The rain in the future is lower than the historical period, and possibly soil moisture deficit will become more common than excess.

While maximum temperatures remain within range, minimum temperatures are lower than ideal, however no effect of these on flowering was observed by farmers, who instead found occasionally temperatures were higher than ideal and causing flower drop.

Stage 4

Pod Formation and Filling
December to January

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 32-38 °C	Tmax: 29-32 °C	Tmax: 29-32 °C	Tmax: 28-31 °C
Tmin: 14-20 °C	Tmin: 12-14 °C	Tmin: 12-15 °C	Tmin: 12-14 °C
Rainfall: 50-60 mm	Rainfall: 3-4 mm	Rainfall: 3-7 mm	Rainfall: 7-14 mm

Figures in Orange indicate deficit rainfall and in Green indicate lower temperatures as compared to the optimal scenario.

During pod formation and filling, maximum temperatures remain well within the range for optimal growth. Minimum temperatures drop below optimal range by 2 °C across all regions. Rainfall is much lower than the required amount, and irrigation is necessary for better crop yield.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 51	Dec Wk 3	T max	30.46	29.40	29.76	29.65	29.82	28.60	28.95	29.49
		T min	13.36	12.31	12.29	12.32	13.43	12.26	13.02	13.14
		Rainfall	0.76	0.82	0.30	0.68	0.44	0.78	1.24	0.51
Week 52	Dec Wk 4	T max	30.21	29.06	29.51	29.41	29.69	28.36	28.74	29.29
		T min	13.21	12.25	12.21	12.27	13.23	12.14	12.90	13.03
		Rainfall	0.17	0.19	0.29	0.41	0.55	0.87	2.36	0.72
Week 1	Jan Wk 1	T max	29.93	28.63	29.11	29.18	29.91	27.85	28.52	29.05
		T min	12.99	12.44	12.54	12.69	13.47	12.41	13.29	13.48
		Rainfall	0.70	1.80	1.24	1.58	1.85	3.69	3.23	1.94
Week 2	Jan Wk 2	T max	30.32	29.02	29.53	29.56	30.38	28.20	28.64	29.37
		T min	12.83	12.25	12.43	12.74	13.50	12.46	13.36	13.51
		Rainfall	0.54	0.46	0.71	0.37	0.70	0.85	2.00	1.50
Week 3	Jan Wk 3	T max	31.11	29.86	30.30	30.35	31.37	29.09	29.43	30.21
		T min	13.19	12.66	12.70	13.20	13.89	12.91	13.67	13.91
		Rainfall	0.15	0.41	0.44	0.33	2.06	0.86	1.15	1.19
Week 4	Jan Wk 4	T max	31.66	30.15	30.74	30.79	32.04	29.37	29.85	30.60
		T min	13.78	12.81	13.06	13.53	14.56	13.16	14.27	14.36
		Rainfall	0.50	0.58	0.45	0.27	0.95	0.93	3.61	1.55
		Total Rainfall	2.82	4.26	3.43	3.64	6.55	7.98	13.59	7.41

Figures in Orange indicate deficit rainfall and in Green indicate lower temperatures as compared to the optimal scenario.

Future Climate Summary (2021-2050)

Climate for optimal growth:	Khandesh	Marathwada	Vidarbha
Tmax: 32-38 °C	Tmax: 33-38 °C	Tmax: 32-38 °C	Tmax: 30-37 °C
Tmin: 14-20 °C	Tmin: 15-20 °C	Tmin: 14-21 °C	Tmin: 15-22 °C
Rainfall: 50-60 mm	Rainfall: 0 mm	Rainfall: 0-1 mm	Rainfall: 3-7 mm

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario.

Maximum temperatures during pod formation and filling do not exceed the range for optimal growth. This is a good sign that gram can cope with the temperatures that are to come, unlike with wheat. Minimum temperatures (or night temperatures) rise by 2 °C in Marathwada and Vidarbha, which may have an impact on plant growth and yield. Rainfall is negligible and a greater amount of irrigation will be required in future years.

District wise Future Climate Data (2021-2050)								
Week of the Year	Month & Week	Variable	Khandesh	Marathwada		Vidarbha		
			Jalgaon	Aurangabad	Jalna	Amravati	Chandrapur	Yavatmal
Week 51	Dec Wk 3	T max	32.94	32.27	33.04	31.80	32.17	29.87
		T min	14.83	14.40	16.01	15.99	16.98	14.72
		Rainfall	0.01	0.01	0.01	0.44	0.32	0.40
Week 52	Dec Wk 4	T max	33.85	33.13	33.93	32.84	33.15	29.94
		T min	15.57	15.10	16.81	16.82	17.80	15.12
		Rainfall	0.00	0.00	0.00	0.46	0.37	0.87
Week 1	Jan Wk 1	T max	34.87	34.05	34.79	33.87	34.25	30.39
		T min	16.86	16.38	18.10	18.02	18.77	15.65
		Rainfall	0.00	0.00	0.07	0.84	0.72	0.49
Week 1	Jan Wk 2	T max	35.82	34.98	35.65	34.77	35.19	30.69
		T min	18.02	17.50	19.17	18.94	19.63	15.82
		Rainfall	0.00	0.00	0.16	1.23	1.42	0.35
Week 1	Jan Wk 3	T max	36.94	36.01	36.71	35.90	36.30	31.18
		T min	19.32	18.68	20.30	20.15	20.85	16.18
		Rainfall	0.03	0.01	0.21	1.36	2.09	0.36
Week 4	Jan Wk 4	T max	37.90	36.90	37.73	37.11	37.49	31.81
		T min	19.91	19.19	20.91	20.91	21.67	16.56
		Rainfall	0.03	0.03	0.22	1.27	2.17	0.50
		Total Rainfall	0.07	0.05	0.67	5.6	7.09	2.97

Figures in Orange indicate deficit rainfall and in Brown indicate higher temperatures as compared to the optimal scenario.

Farmer Observations

- If it is not cold enough and there are pod borer attacks.
- Pods do not fill well at higher temperatures, and grains remain small and white, which sell at a lower rate.
- Even if the crop has been sufficiently irrigated at the start of this stage, if temperature suddenly rises, the soil moisture dries up and the pods do not fill as much.
- Fog during this period leads to increased incidences of diseases.
- Sometimes there is a high incidence of weeds and farmers have started leaving more space between crops in response, to have room to weed.

Inference

While future temperatures remain within acceptable range for optimal growth, they are certainly higher than historical temperatures in the same weeks. This rise in temperature not only has a negative effect on pod filling, but also compounds plant stress by leading to a reduction of soil moisture. This is an alarming trend that needs to be addressed. Rainfall is projected to decline even further than what it presently is, which will increase groundwater extraction for irrigation.

Stage 5

Maturity
February

Historical Climate Summary (1989-2018)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 30-41 °C	Tmax: 31-33 °C	Tmax: 31-34 °C	Tmax: 30-33 °C
Tmin: 17-25 °C	Tmin: 14-15 °C	Tmin: 14-17 °C	Tmin: 14-17 °C
Rainfall: 0-5 mm	Rainfall: 1-2 mm	Rainfall: 1-4 mm	Rainfall: 4-8 mm

Figures in Green indicate lower temperatures and in Blue indicate excess rainfall as compared to the optimal scenario.

Maximum temperatures are well within the acceptable range for optimal growth. Minimum temperatures are lower than optimal across all the regions, and rainfall is within acceptable range except for Chandrapur and Yavatmal district which received higher than optimal rainfall.

District wise Historical Climate Data (1989-2018)

Week of the Year	Month & Week	Variable	Khandesh		Marathwada			Vidarbha		
			Dhule	Jalgaon	Aurangabad	Jalna	Nanded	Amravati	Chandrapur	Yavatmal
Week 5	Feb Wk 1	T max	32.54	30.89	31.56	31.46	32.89	30.19	30.53	31.32
		T min	14.54	13.53	13.78	14.09	15.50	13.83	14.88	14.90
		Rainfall	0.13	0.23	0.27	0.32	1.77	1.56	2.64	3.45
Week 6	Feb Wk 2	T max	33.00	31.59	32.05	32.10	33.57	30.93	31.45	32.09
		T min	14.94	14.37	14.45	14.93	16.38	14.81	16.02	16.02
		Rainfall	0.44	0.64	0.46	0.29	0.65	0.83	2.29	1.06
Week 7	Feb Wk 3	T max	33.40	32.21	32.80	32.71	34.46	31.52	32.10	32.72
		T min	15.43	15.00	15.14	15.54	16.87	15.34	16.62	16.57
		Rainfall	0.80	1.17	0.55	0.34	1.08	1.65	2.57	1.89
		Total Rainfall	1.37	2.04	1.28	0.95	3.5	4.04	7.5	6.4

Figures in Green indicate lower temperatures and in Blue indicate excess rainfall as compared to the optimal scenario.

Future Climate Summary (2021-2050)			
Climate for optimal growth:	**Khandesh**	**Marathwada**	**Vidarbha**
Tmax: 30-41 °C	Tmax: 39-40 °C	Tmax: 38-40 °C	Tmax: 33-40 °C
Tmin: 17-25 °C	Tmin: 21-22 °C	Tmin: 20-23 °C	Tmin: 17-24 °C
Rainfall: 0-5 mm	Rainfall: 0 mm	Rainfall: 0-1 mm	Rainfall: 1-5 mm

Rainfall, maximum temperature and minimum temperature are all within the ranges for optimal growth in the future across all the three regions.

District wise Future Climate Data (2021-2050)								
Week of the Year	**Month & Week**	**Variable**	**Khandesh**	**Marathwada**		**Vidarbha**		
			Jalgaon	**Aurangabad**	**Jalna**	**Amravati**	**Chandrapur**	**Yavatmal**
Week 5	Feb Wk 1	T max	38.64	37.53	38.42	38.06	38.37	32.64
		T min	20.57	19.82	21.57	21.71	22.44	17.01
		Rainfall	0.00	0.04	0.35	1.58	2.28	0.21
Week 6	Feb Wk 2	T max	39.36	38.18	39.13	38.88	39.23	33.62
		T min	21.23	20.48	22.32	22.49	23.30	17.80
		Rainfall	0.07	0.03	0.13	0.83	1.41	0.21
Week 7	Feb Wk 3	T max	40.17	38.89	39.82	39.79	40.11	34.46
		T min	22.26	21.34	23.19	23.52	24.43	18.84
		Rainfall	0.04	0.04	0.13	0.61	1.83	0.41
		Total Rainfall	0.11	0.11	0.61	3.02	5.52	0.83

Farmer Observations

- Farmers have observed untimely rain destroying harvests in recent years.
- When gram has been laid out in the fields to dry, it is vulnerable to rainfall, and rain during this time leads to fungal diseases and germination of gram grains through the pods right in the fields themselves.
- Harvested grain left to dry is also impacted by unseasonal rainfall which increases incidences of fungal disease.

Inference

Farmers have observed that rain during harvest time causes loss and degradation of grain in recent years. This is a serious issue, but we can infer from future rainfall projections that this issue may reduce due to a decrease in rainfall in the coming years. The temperatures both historically and in the future did not exceed the optimal range, which is a positive indication that gram may be able to handle the increasing temperatures coming up ahead.

3.4.2 Summary and Discussion

A summary of the climate risks found through climate analyses and farmer validation is given below:

Summary of Climate Effects

Stage 1: Sowing and Emergence	Stage 2: Vegetative Growth	Stage 3: Flowering	Stage 4: Pod Formation and Filling	Stage 5: Maturity
*Week: 42,43 Oct weeks: 3,4	*Week: 44,45,46,47,48 Nov weeks: 1,2,3,4,5	*Week: 49,50 Dec weeks: 1,2	*Week: 51,52,1,2,3,4 Dec weeks: 3,4 Jan weeks: 1,2,3,4	*Week: 5,6,7 Feb weeks: 1,2,3
				
PRESENT CLIMATE RISKS				
Slightly excess rainfall	Insufficient rainfall Warming temperatures		Sudden warming and low rainfall	Harvest destruction by rainfall
IMPACTS				
Fungal disease, chickpea wilt	Increased pod borer attacks		Drying out of the crop Yield loss	Yield loss Profit reduction
ADAPTATIONS				
Increased spraying Seed treatment	Increased spraying		Increased irrigation	
FUTURE CLIMATE RISKS				
Low rainfall	Low rainfall		Rising minimum temperatures Negligible rainfall	
** Denotes week of the year*				

Discussion

Compared to wheat, gram is tolerant of higher temperatures and hence does not have as negative a relationship with projected temperatures. Gram is both sown and harvested before wheat, and escapes some of the extremely high temperatures of March. Many farmers that grow wheat also grow gram, and find gram to also be an inexpensive crop with low inputs. There is an increase in the pesticides used recently, to combat the pod borer and chickpea wilt, but other than that it is a low input crop and requires one time fertilizer application.

An important point to highlight here is the relationship of gram cultivation to soil. Like soybean, gram is a legume, and through a symbiotic relationship with bacteria in its roots, it can fix 80% of its own nitrogen requirement from atmospheric nitrogen. The bacteria it associates with are in structures on the roots called nodules, and nodule formation is an important part of early vegetative growth. If the soil temperature during this time is high, it affects nodule formation, leading to crop damage. Soil structure also plays a role in the cultivation of gram. If soils are black and deep, as they are in some places in Maharashtra, they can potentially hold sufficient moisture to grow gram without irrigation. Since most soils in our study region have been degraded and have low soil moisture holding capacity, the reduction of Rabi rainfall has necessitated irrigation to grow gram. Additionally, sensitive plant stages like flowering are affected negatively by both excess and insufficient soil moisture, and these states are exacerbated in degraded soils. A serious effort to improve soil fertility across the three regions must be undertaken, and will benefit all crops grown, especially gram.

As mentioned above, gram is a comparatively heat-tolerant cold season crop, but is still negatively affected by high temperatures. Gram flowers self-pollinate before opening, and high temperatures during flowering lead to abscission of flowers, buds and pods. High temperatures after flowers opening cause low pod weight, and most cultivars of gram do not set pod over 35 °C. Both historical and future temperatures remain below this in the early weeks of the pod formation stage. Towards the end of pod filling, however, temperatures are projected reach 37-38 °C, and breeding varieties that can perform well in such conditions is important to adapt to the future climate.

Drought conditions account for 50% of global yield reduction in gram, and in most places, despite irrigation gram is grown in low nutrient and low soil moisture conditions. Often, cultivars grown are adapted to these conditions, and do not respond well to high input conditions. Finding cultivars that respond well to increased soil moisture is key for the future. In addition, methods to irrigate gram crops adequately mush not endanger the already strained groundwater supply. With decreasing winter rain, and less water percolation through soil, gram poses the same challenge to groundwater that wheat does.

With rising temperatures, gram is facing increasing pressure from weeds, pests and disease. These are usually suppressed by cold weather, but with warming winter temperatures, there is increasing incidence of pod borers, chickpea wilt and weeds. Gram is a poor competitor of weeds, and these must be vigilantly removed. If not addressed, chickpea wilt can affect all plants in a field and lead to crop destruction even before flowering. The rising temperatures are leading to an increase in labour and chemical use by farmers. Seed treatments have become necessary.

Overall, rising temperatures and decreasing rainfall pose the main climate related threats to gram. Cloudy conditions, excess rainfall at the time of harvesting and excess soil moisture during early vegetative stage are the other challenges gram faces. However, it remains a relatively low input crop for the Rabi season, and looks like it can handle most of the challenges the future climate will bring, as long as pests are controlled.

4
Synthesis

4.1 Summary

Climate change impacts, mainly in form of fluctuations in temperature and rainfall patterns is likely to be detrimental for the growth and development for each of the four crops - Soybean, Cotton, Wheat and Gram in Maharashtra. The section below summarizes the key impacts for each of the crops based on the analysis of climate data and farmer interactions.

Soybean

Soybean cultivation is currently impacted by high rainfall during the vegetative and reproductive stages, leading to high incidence of fungal diseases and pests. At least one additional spraying is caused by excess rain. Some farmers also face a loss of yield due to inadequate soil moisture, and many report a loss in yields from untimely rainfall during the harvest period. Future climate predictions show an excess of rain until flowering, and then suddenly a deficit of rain during pod development and maturity. This will be detrimental for the plant and will have an impact on production.

Cotton

Cotton crop faces challenges similar to Soybean, of excess and erratic rainfall in the early months of emergence, vegetative growth, square formation and flowering combined with high temperatures. This creates an atmosphere for pests to thrive in, and high amounts of chemical pesticides are used. Inadequate soil moisture at the time of boll setting and filling, and then cotton boll degradation from rain during harvest causes yield loss. Future climate predictions show an excess of rainfall and high temperatures till square formation, and then high temperatures and inadequate rainfall for the rest of the cotton season. Cotton requires water during the later stages of boll formation and setting, and rainfall deficit towards the end of the season have the potential to severely impact production.

Wheat

Wheat cultivation is impacted by low rainfall at the time of sowing, insufficient cold spell during vegetative growth, excess rainfall and strong winds during grain ripening, and loss in yield from rain at the time of harvest. The biggest challenge for wheat cultivation in the years to come is high temperatures at the time of grain ripening. Grain weight goes down with a rise in temperature, and temperatures during the time of grain filling are predicted to reach 42 °C. Rainfall during the entire rabi cropping season is negligible, and all of the water requirement of wheat, including pre-sowing soil moisture, must come from irrigation. This situation puts enormous pressure on groundwater resources and will lead to depletion of aquifers in the years to come.

Gram

Gram crop suffers from excess soil moisture before planting leading to an increase in fungal diseases, and insufficient cold weather causing a reduction in yield. During pod filling, temperatures may suddenly rise and dry out soil, causing pods to fill less. Gram also experiences rainfall during harvest leading to loss in yield. In the future, cultivation of gram will be impacted during pod filling stage due to rising temperatures resulting in reduced filling. Gram is tolerant of slightly higher temperatures than wheat, and escapes some high temperatures as it is harvested earlier than wheat, but has increased incidences of pest attacks, and requires pesticide use. Gram crop will also face extremely low rainfall throughout the rabi season, and will completely depend on irrigation for soil moisture requirements.

4.2 Way forward

Reducing the impacts of changing climate on the cultivation of the four crops will require effort in areas of recording granular climate data, integrating those in informing farming decisions, improving quality of inputs, enhancing knowledge on better cultivation practices, and adoption of better management practices for resource conservation amongst others. Some of the immediate actions which need to be considered are listed below:

Collection of highly localized climate data

Access to local and accurate climate data is valuable in understanding and accurately predicting trends of climate for an area. Despite the close proximity of Amravati and Nanded District to Yavatmal, their climate trends both historical and future show considerable variation. While broad climate data for regions or even the State of Maharashtra are informative, the climate experienced at the village level is most relevant to farmers. Having weather stations in each village collecting data, and having that data easily accessible to both residents of the village physically and to stakeholders across academia, government and industry in an online repository is an important first step to accurately map the effects of climate change on crops. While it is important to have local climate data, what is equally important is to generate timely advisories based on models that can automatically be applied to these data and provide accurate predictions, advisories and warnings to farmers at a village level.

Improving quality of inputs

Improving the quality of seed, pesticide, herbicide and fertilizer available to farmers will help increase the yield of crops. The unpredictability of the onset of monsoon and double sowing and gap filling reported by farmers show that poor quality seeds with high germination loss rates need to be replaced with hardy seeds with low germination loss and clear instructions on how they are to be planted for best results. Access to soil testing based fertilizer recommendations must be improved, along with promotion of well-rounded fertilizers providing essential macro and micro nutrients. Increasing temperatures and erratic rainfall lead to a favourable environment for weeds, pests and disease, and farmers have increased pesticide spraying in response. Dependence on chemical pesticides and fertilizers must be addressed, and efforts to promote effective bio fertilizers, organic manures and bio pesticides must continue.

Dissemination of better management practices

For each of the crops, detailed Integrated Pest Management and Integrated Nutrient Management plans have already been published, but need to be popularized at a granular level throughout Maharashtra. Farmers need to have easy access to information networks on current issues faced. Changing the current practices to inform and adapt will be crucial to combat climate change.

Improved access to technology

Farmers will benefit greatly from access to advanced technologies developed to reduce the burden of traditional agriculture, but they undeniably need access to basic technology. Further development of warehouses where farmers can safely store grain to prevent water and rodent damage, and access to basic information technology must be provided. Well-developed network of access to good quality seeds, and market access for all crops must also be promoted.

Improving soil fertility

Having good soil structure and fertility can help combat the erratic rainfall and plant stress conditions predicted in the future. Fertile and deep soil can recharge groundwater, and deal with the mismatch between actual rainfall and optimal rainfall. Plants that are healthy and not stressed are better able to combat disease and pests, and having soils containing all required nutrients in balanced amounts is essential. Soils with beneficial micro-organisms will also help crop plants to obtain the nutrients they require. A simple way to increase soil fertility is the continuous addition of organic matter.

Enhancing rainwater harvesting and groundwater recharge

In the future, rainfall is concentrated in the months of June to August, with rainfall dropping September onward. The rabi season – October to March is predicted to receive almost no rainfall, and agriculture in the months September onward will become completely dependent on irrigation. Most of this irrigation will come from groundwater sources. It is of the utmost importance to focus on groundwater recharge through successful rainwater harvesting, and spreading these practices in every village. Without this, both human life, livestock and crops will suffer from poor access to water. Improved access to micro-irrigation systems to farmers in all regions of Maharashtra will improve ability to supply adequate water to crops, and enable farmers to efficiently manage precious groundwater resources.

Creating improved crop varieties for cultivation

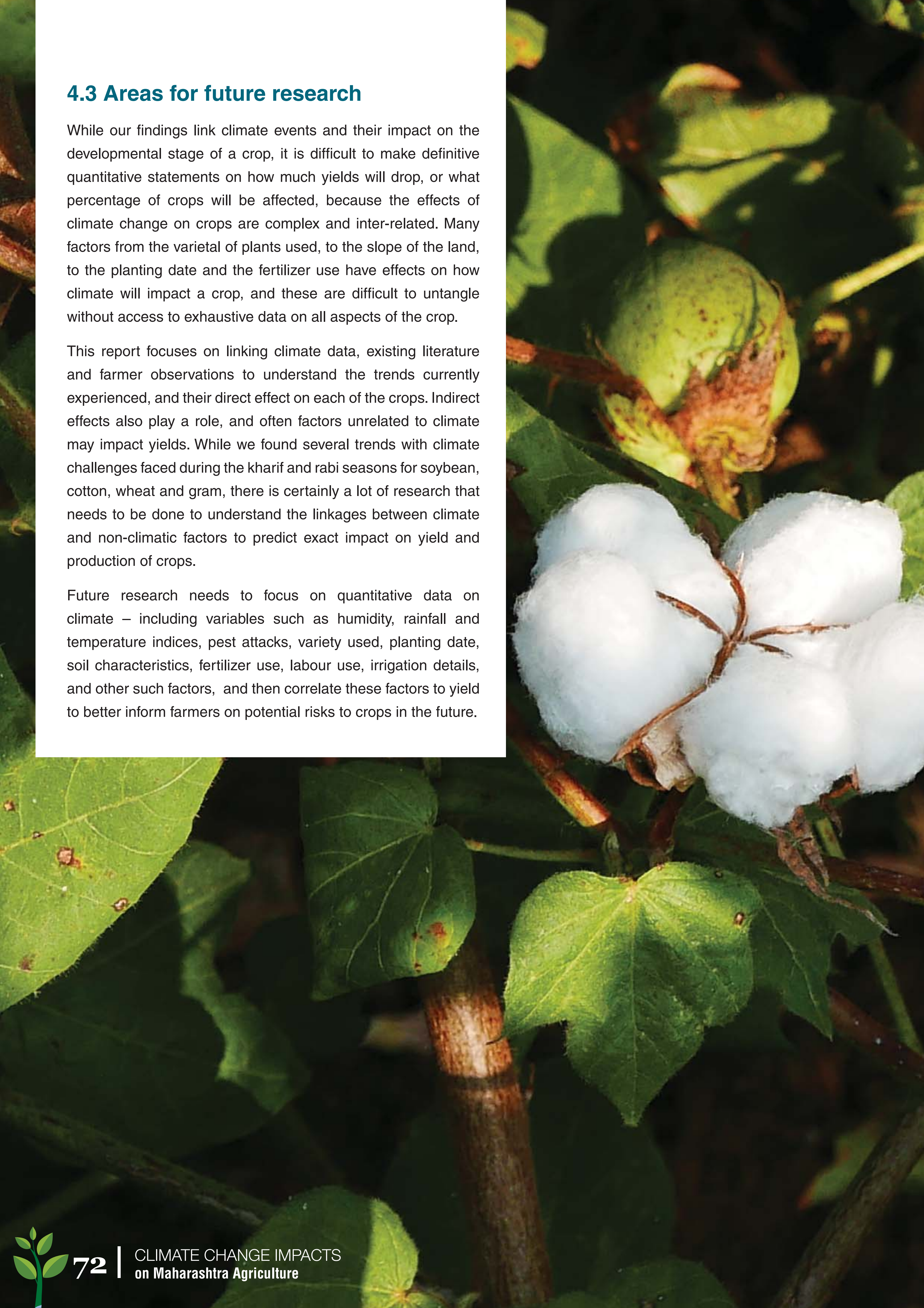
Finally, providing farmers with access to crop varieties suited to rising temperatures and resistant to water shock must be a priority. Plants have amazing capacity to adapt to adverse conditions, but it takes time for the right combination of traits to be achieved. There are many global and regional efforts to create heat and drought tolerant varieties, and further development of such varieties suited to the semi-arid regions of Maharashtra has been undertaken. Shorter duration and heat tolerant wheat and gram, and pest and water stress tolerant soybean and cotton may be a better choices of varieties for the future. Making these resilient crop varieties and pertinent information on what type of environment they are suited to, available to farmers is essential for their ability to maintain yields in light of the future climatic changes.

4.3 Areas for future research

While our findings link climate events and their impact on the developmental stage of a crop, it is difficult to make definitive quantitative statements on how much yields will drop, or what percentage of crops will be affected, because the effects of climate change on crops are complex and inter-related. Many factors from the varietal of plants used, to the slope of the land, to the planting date and the fertilizer use have effects on how climate will impact a crop, and these are difficult to untangle without access to exhaustive data on all aspects of the crop.

This report focuses on linking climate data, existing literature and farmer observations to understand the trends currently experienced, and their direct effect on each of the crops. Indirect effects also play a role, and often factors unrelated to climate may impact yields. While we found several trends with climate challenges faced during the kharif and rabi seasons for soybean, cotton, wheat and gram, there is certainly a lot of research that needs to be done to understand the linkages between climate and non-climatic factors to predict exact impact on yield and production of crops.

Future research needs to focus on quantitative data on climate – including variables such as humidity, rainfall and temperature indices, pest attacks, variety used, planting date, soil characteristics, fertilizer use, labour use, irrigation details, and other such factors, and then correlate these factors to yield to better inform farmers on potential risks to crops in the future.



References

1

Susan Callery. “Effects | Facts – Climate Change: Vital Signs of the Planet.” *NASA*, 2020, https://climate.nasa.gov/effects/.

World Bank. *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience. A Report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics.* 2013.

1.1

Directorate of Economics and Statistics. *Agricultural Statistics at a Glance 2018*. 2020.

Directorate of Economics and Statistics. *Economic Survey of Maharashtra 2020-21.* 2021.

Sinha, D. K. 20 *Agro-Ecological Regions of India (Explained With Maps)*. http://www.ide-india.org/sites/default/files/20 agro ecological regions of India.pdf. Accessed 25 June 2021.

Todmal, Rahul S. “Droughts and Agriculture in the Semi-Arid Region of Maharashtra, Western India.” *Weather, Climate, and Society*, vol. 11, no. 4, American Meteorological Society, Oct. 2019, pp. 741–54, doi:10.1175/WCAS-D-18-0131.1.

Udmale, Parmeshwar D., et al. “Drought Impacts and Adaptation Strategies for Agriculture and Rural Livelihood in the Maharashtra State of India.” *The Open Agriculture Journal*, vol. 8, 2014, pp. 41–47.

1.2

De Lima, Cicero Z., et al. “Heat Stress on Agricultural Workers Exacerbates Crop Impacts of Climate Change.” *Environmental Research Letters*, vol. 16, no. 4, IOP Publishing Ltd, Apr. 2021, p. 44020, doi:10.1088/1748-9326/abeb9f.

Ghude, Sachin D., et al. “Reductions in India’s Crop Yield Due to Ozone.” *Geophysical Research Letters*, vol. 41, no. 15, Blackwell Publishing Ltd, Aug. 2014, pp. 5685–91, doi:10.1002/2014GL060930.

Annih Grace, Mbong, et al. “An Overview of the Impact of Climate Change on Pathogens, Pest of Crops on Sustainable Food Biosecurity.” *International Journal of Ecotoxicology and Ecobiology*, vol. 4, no. 4, Science Publishing Group, 2019, p. 114, doi:10.11648/j.ijee.20190404.15.

Lobell, David B., and Sharon M. Gourdji. “The Influence of Climate Change on Global Crop Productivity.” *Plant Physiology*, vol. 160, 2012, pp. 1686–97, doi:10.1104/pp.112.208298.

Devasirvatham, V., et al. “High Temperature Tolerance in Chickpea and Its Implications for Plant Improvement.” *Crop and Pasture Science*, vol. 63, no. 5, CSIRO PUBLISHING, July 2012, pp. 419–22, doi:10.1071/CP11218.

Luo, Qunying, et al. “Cotton Crop Phenology in a New Temperature Regime.” *Ecological Modelling*, vol. 285, Elsevier, Aug. 2014, pp. 22–29, doi:10.1016/j.ecolmodel.2014.04.018.

K Sankaranarayanan, et al. “Climate Change and Its Impact on Cotton (Gossypium Sp.).” *Indian Journal of Agricultural Sciences*, vol. 80, no. 7, 2010, pp. 561–75, https://www.researchgate.net/publication/278405215_Climate_change_and_its_impact_on_cotton_Gossypium_sp.

1.3

Mula MG. *Chickpea Production in India*. 2010.

Gaur PM, et al. *Chickpea Seed Production Manual*. 2010, p. 28, www.icrisat.org.

Ramadas, Sendhil, et al. “Wheat Production in India: Trends and Prospects.” *Recent Advances in Grain Crops Research*, IntechOpen, 2020, doi:10.5772/intechopen.86341.

Agarwal, Dinesh K., et al. “Soybean: Introduction, Improvement, and Utilization in India-Problems and Prospects.” *Agricultural Research*, vol. 2, no. 4, Springer, Dec. 2013, pp. 293–300, doi:10.1007/s40003-013-0088-0.

Soybean Processors Association of India. *District Wise Details*. http://www.sopa.org/district-wise-details/?arrive=2020&state=Maharashtra&path=http://www.sopa.org/soybean-hectares-planted&submit=Search. Accessed 26 June 2021.

Jain, Bhavika. “Maharashtra Farmers: Bt Cotton Falling to Pest, Maharashtra Tensed.” *Times of India*, 2017, https://timesofindia.indiatimes.com/city/mumbai/bt-cotton-falling-to-pest-maharashtra-tensed/articleshow/59449010.cms.

YourArticleLibrary. *Cotton Cultivation in India: Conditions, Types, Production and Distribution*. https://www.yourarticlelibrary.com/cultivation/cotton-cultivation-in-india-conditions-types-production-and-distribution/20949. Accessed 25 June 2021.

Agri Farming. *Cotton Farming Guide; Planting; Care; Yield; Harvesting*. https://www.agrifarming.in/cotton-farming-guide. Accessed 25 June 2021.

Suresh, A., et al. “Risks in Rainfed Agriculture and Farmers’ Adaptation Practices: A Case of Cotton Farmers of Maharashtra.” *Indian Journal of Agricultural Economics*, vol. 72, no. 3, 2017, pp. 362–74.

Asia Farming. Cotton Cultivation; Planting, Harvesting Guide. https://www.asiafarming.com/cotton-cultivation-beginners. Accessed 25 June 2021.

3.1

B. U. Dupare, et al. “Strategy for Increasing the Soybean Productivity through Frontline Demonstrations and Its Role in Soybean Economy of India in Changed Climatic Scenario.” *International Journal of Extension Education*, vol. 13, 2017, pp. 76–82.

IndiaAgronet. *Soyabean Crop Cultivation Guide*. https://www.indiaagronet.com/indiaagronet/Crop_Husbandry/contents/soybean.htm. Accessed 26 June 2021.

Pasley, Heather R., et al. “Modeling Flood-Induced Stress in Soybeans.” *Frontiers in Plant Science*, vol. 11, Frontiers Media SA, Feb. 2020, p. 62, doi:10.3389/fpls.2020.00062.

Rao, V. U. M., et al. *District Level Crop Weather Calendars of Major Crops in India*. 2015.

Sharma, A. N., et al. *Integrated Pest Management for Soyabean*. 2014.

Vadez, Vincent, and Jana Kholova. “Understanding Crop Physiological Processes for Climate Resilience.” *Lead Papers Vol 4: 4th International Agronomy Congress*, th International Agronomy Congress, 2016, pp. 55–58, doi:10.2135/cropsci2009.

3.2

Dhaliwal, G. S., et al. “Insect Pest Problems and Crop Losses: Changing Trends.” *Indian Journal of Ecology*, vol. 37, 2010, pp. 1–7, https://www.researchgate.net/publication/281477003_Insect_pest_problems_and_crop_losses_Changing_trends/citation/download.

Ingole, Akshay Jaydevrao. *Studies on Nutrient Status of Cotton Growing Soil and Cotton Crop in Nanded District of Maharashtra*. Vasantrao Naik Marathwada Krishi Vidyapeeth, 2018, https://krishikosh.egranth.ac.in/displaybitstream?handle=1/5810070599&fileid=70fd066f-8812-4b82-a549-b6116236c20b.

3.3

Behera, U. K., et al. “Evaluation of Heat Stress and Leaf Rust Tolerance between Very Late Planted Durum and Bread Wheat Cultivars in Central India.” *Australian Journal of Experimental Agriculture*, vol. 47, no. 12, CSIRO PUBLISHING, Nov. 2007, pp. 1422–34, doi:10.1071/EA06323.

Farmers’ Portal. *Wheat*. https://farmer.gov.in/M_cropstaticswheat.aspx. Accessed 26 June 2021.

Knott, Carrie A. *Identifying Wheat Growth Stages*. 2016.

Mehta Rashmi, and Pandey Vyas. “Reference Evapotranspiration (ETo) and Crop Water Requirement (ETc) of Wheat and Maize in Gujarat.” *Journal of Agrometeorology*, vol. 17, no. 1, 2015, pp. 107–13, https://www.researchgate.net/publication/278245013_Reference_evapotranspiration_ETo_and_crop_water_requirement_ETc_of_wheat_and_maize_in_Gujarat.

Mitra, R., and C. R. Bhatia. “Bioenergetic Cost of Heat Tolerance in Wheat Crop.” *Current Science*, vol. 94, no. 8, 2008, pp. 1049–53.

Texas A&M Extension Center at San Angelo. *Growth Stages of Wheat*. https://sanangelo.tamu.edu/extension/agronomy/agronomy-publications/growth-stages-of-wheat/. Accessed 26 June 2021.

3.4

Devasirvatham, V., et al. “High Temperature Tolerance in Chickpea and Its Implications for Plant Improvement.” *Crop and Pasture Science*, vol. 63, no. 5, 2012, doi:10.1071/CP11218.

Directorate of Pulses Development. *Chickpea Production Technology*. 2017, https://farmer.gov.in/imagedefault/Other_Pulses/Chickpea_E.pdf.

Kumbhar, Nitin, et al. *Climate Resilient Agricultural Technologies for Paddy and Chickpea in Sakri Block, Dhule District in Maharashtra*. Watershed Organisation Trust, 2018.

Singh, K. B. “Chickpea (Cicer Arietinum L.).” *Field Crops Research*, vol. 53, no. 1–3, Elsevier, July 1997, pp. 161–70, doi:10.1016/S0378-4290(97)00029-4.

For further details, contact

Romit Sen
Associate Director - Water and Agriculture
Institute for Sustainable Communities
Email: rsen@sustain.org

Chaiti Bhagawat
Program Assistant - Water and Agriculture
Institute for Sustainable Communities
Email: cbhagawat@sustain.org