Assessment of Climate Change Impact on Agricultural Crops' Growth and Yield Over Indian Subcontinent Using Remote Sensing, GIS and Modelling Approach

Atin Majumder, Sony Bora, P. K. Kingra, and Agniva Mandal

Abstract Clear proof of climate change's existence has been shown over the past decade, and it is having an influence everywhere. As a result, the scientific community is placing more and more attention on food security and its regional effects. In the face of climate change, food production and supply are likely to be most vulnerable. Agricultural systems need to opt for measures that not only boost food supply to feed the worldwide growing population but also nullify the destructive impacts on earth and humankind. In future, under the effect of global warming, plant transpiration and soil evaporation are likely to greatly alter water productivity. The climate science community is facing the significant challenge of dealing with a continuously changing observing system. In India, significant research has been done to comprehend the nature and expanse of variations experienced in yield of various crops due to projected climate change. To analyse the potential impact of changing climate on agriculture, the advent of remote sensing techniques along with GIS and crop simulation models have proven to be a boon for the agriculture sector. Different crop simulation models can be employed in crop improvement programmes by modifying the characteristics showing the most significant effect on yield. It provides informative strategies to avoid risks imposed by climate variations but also helps in understanding the bio-phyical processes. These models can project the possible impacts of climate change on future crop productivity and inspect the mitigation measures that will guide the farmers and policy makers towards proper decision making. Similarly, remote

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sensing can assess the impacts of climate change on various spatial and temporal scales that help in monitoring and forecasting the agricultural production and also help in substantial resource management. Hence, Crop models and remote sensing are efficient tools for coping with the challenges of climate change on agriculture.

Keywords Climate change · Crop yield and growth · Remote sensing · Simulation models

1 Introduction

1.1 Climate Impact and Food Security

Climate change refers to deviation from the average atmospheric conditions caused by both natural and artificial factors. Natural factors include orbit of earth's revolution, crustal movements and volcanic activities whereas, artificial factors include the accumulation of greenhouse gases and the aerosol. Changing climate scenarios hamper the global food production system. It affects four main dimensions of food system: food production, availability, accessibility and utilization. Climate change led extreme weather events have doubled since the early 1990s. Higher ocean and land temperatures, depleting ground water table, greater carbon dioxide concentrations, frequent droughts and floods have already started to show its impact on staple crops around the globe. This can be due to the presence of huge amount of greenhouse gases in the lower troposphere. The two primary causes are the adoption of intensive agriculture to satisfy the rising food demand, which is frequently accompanied by deforestation, and the burning of fossil fuels (coal, oil, and gas) to meet the rising energy demand. First, agriculture generates the food that people consume, and second, it is the major source of income for 40–50% of the population, making it essential for food security. Long-term climate changes adversely impact food production- more than any of the other sectors of global economy. In developing countries, the impact to agriculture from disasters accounts for 63% [18].

Agriculture and food production are impacted by climate change in a variety of ways. Changes in agro-ecological conditions have a direct impact on food production, while income development and distribution have an indirect impact on food demand. Higher temperatures reduce yields along with encouraging weed and pest proliferation. Further it may result into shifts in the geographical distribution of certain pests. Extreme periods of high temperature are harmful, particularly during the flowering stage, because if this critical stage is disrupted, there may be no seed production. Variability in rainfall patterns like droughts in some region and torrential rains and flooding in other regions may induce crop failure in short term and subdue the long term crop production. In coastal areas, increasing sea level may lead to complete loss of agricultural land. Although climate change can show positive impacts in some of the crops in some regions of the world. It is anticipated that climate change events like heat and cold waves during anthesis stage would have negative effects generally on agriculture, which ultimaterly threatening the global food security. Different crops behave differently to the changing climate. For instance, photosynthesis in C3 crops like wheat, rice, soybeans, etc., can get enhanced due to carbon emissions, whereas C4 crops like sugarcane, maize, etc., don't behave similarly.

2 Climate Change Impact on Agriculture

To quantify the consequences of climate change and environmental variation, data on the frequency of stress events, their impact on day-to-day activities, and harm to agricultural products are gathered. Harsh impacts on plant production are becoming more severe as a result of both direct and indirect effects of abiotic stressors in response to quick changes in environmental conditions. CO_2 concentrations are expected to rise from 400 to 800 mol^{-1} by the end of the century, due to continued deforestation and excessive usage of fossil fuels [54]. Studies predict that during the next 30 years, the earth's average surface temperature will increase by 0.2 °C per decade [56]. In addition, by the end of this century, it is anticipated that the temperature of greenhouse gases in the atmosphere will have increased by 2.5–4.5 °C [25]. According to the recent sixth assessment report of IPCC "It is only possible to avoid warming of 1.5 °C or 2 °C if massive and immediate cuts in greenhouse gas emissions are made and to achieve that the world would need to cut emissions by 50% by the year 2030 and by 100% by the year 2050" [26]. The root causes of climate change and its effect on agriculture and its related industries have been discussed in Fig. 1.

The combination of unpredictable rainfall, drought, and increasing extreme weather is predicted to have a significant negative impact on agriculture. The agricultural industry is one of the main producers of greenhouse gases. In exchange, the climate has the capacity to change crop yields both directly and indirectly through the provision of fertiliser, pests, and diseases, among other abiotic stressors including heat stress and water stress [39]. The majority of people throughout the world perceive cereal grains like wheat, maize, and rice to be staple foods. By raising plant respiration rates, global warming is diminishing the net assimilation of carbon, which might reduce agricultural yields and potentially lead to the invasion of weeds, diseases, and pests [5]. Various implications of climate change in agriculture are discussed here [34].

According to global statistics, crop productivity will decline by 10–40% by 2100.

By the middle of the twenty-first century, South Asian nations should expect an average 30% decline in agricultural production. Increased temperature would necessitate more fertilizer to achieve the same production goals, resulting in increased emissions.

Productivity of cereals in Indo-Gangetic plains showed declining trends due to rise in temperature and decrease in water availability.

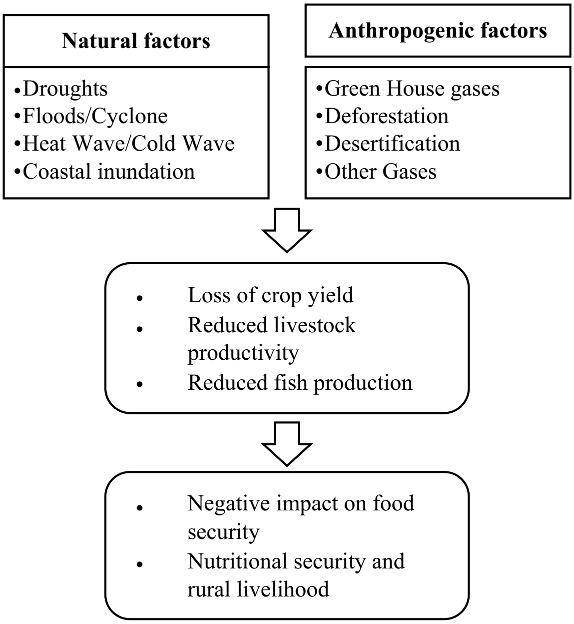

Fig. 1 Climate change's root causes and effects on agriculture and related industries

Rabi crops are projected to have a higher loss due to increase in minimum temperature. Wheat production is reduced by 4–5 million tons for every 1 °C increase in temperature. If farmers could plant in time, the loss would be only 1–2 million tons.

Less frost damage: potato, peas, and mustard will suffer less harm.

Rising river and sea water temperature highly affected the spawning, migration, and harvests of fishes. Coral reefs are also projected to deteriorate till 2030.

3 Sector Wise Impact of Climate Change

3.1 Agriculture

Temperature variations during the growing season can result in catastrophic crop losses. The rate of development will be accelerated as the temperature rises. The time between sowing and harvesting for an annual crop will be shorter. Because of shortening of this cycle, senescence will occur sooner, which could negatively impact output [21]. "During the cultivation of wheat, an increase in temperature by 1 °C could reduce production yields by 3–10%" [58]. Temperature of 30 °C during wheat's flowering and grain filling stages can severely impact seed set and weight [9]. According to Sun et al. [51] heat stress (>30 °C) during the reproductive stage of wheat results in a significant reduction in number of seed, also a stress exposure from 2 to 30 days can alter the seed weight significantly. "Furthermore, a meta-analysis indicated that yield loss may occur with the rise of every 2 °C of temperature in sub-tropical and temperate regions" [1]. In India, a rise in temperature of 1.5 °C and a fall in precipitation of 2 mm result in a 3–15% reduction in rice productivity [3]. In India, rainfed rice yields are expected to decrease by somewhat 2.5% in 2050 and 2080, but irrigated rice yields are expected to increase by 7% in 2050 and 10% in 2080 scenarios. Wheat yields are expected to drop by 6–25% by 2100, while maize yields will drop by 18–23%. Chickpeas are anticipated to profit from future climates as their yield rises (23–54%) [35]. According to Singh [48] exposure of rice to 1 °C for more than one hour can produce sterile grains. According to studies on the impact of global warming on agricultural output in India, yields of wheat, rice, and maize decreased by 5%, 6–8%, and 10–30%, respectively [33].

Heat stress combined with drought condition at the time of seed development can reduce the seed weight, seed number and seed setting in legumes and as well as in cereals [6, 7, 45]. The studies of Daryanto et al. [14] found that cereals often survive drought better than legumes, tubers and root crops. Except for wheat, which was sensitive during the vegetative phase, most crops were more sensitive to drought during their reproductive (i.e., grain filling, tuber beginning) than during their vegetative phase. The most severe effects of climate change are anticipated to be felt by cereal crops like wheat and rice, whereas legumes like soybean and peanuts are expected to benefit from the shift in temperature. By 2030, soybean yields are expected to increase by 8–13%, and groundnut yields up to 7% [44].

3.2 Horticulture

When vegetable crops are subjected to extremely high temperatures, transpiration loss enhances, fruit set in citrus fruits gets limited and burning or scorching of blooms, especially on young trees occurs. In litchi plantations, temperature increases during the ripening stage cause fruit burning and cracking. It also causes moisture stress on fruit trees such as apples, apricots and cherries resulting in physiological disorders like sunburn [30]. Vegetable crop yields will be lowered by 5–15% if ozone level exceed 50 parts per billion per day [40]. The projected impact of climate change on horticulture are as follows.

The areas presently favourable for horticultural crops would become unfavourable in another 25 years.

Production timings may change due to rise in global surface temperature.

Higher temperatures will impair tuber initiation in potatoes, tomato quality, and pollination in various crops. It may lead to bolting in case of crucifers; reduced anthocyanin production in apples and capsicum; blossom end rot and tip burn in tomatoes.

A greater temperature may negatively affect pollination, resulting in floral abortions, fruit and blossom drop, and other problems. With increase in temperature, crops in temperate regions will experience reduced chilling and cold injuries.

The annual irrigation demand will rise, and the heat unit requirement will be met in a much shorter period of time. Elevated temperature will induce annual irrigation demand and heat unit requirement will fulfil in much shorter duration.

3.3 Fruits

Yields of several horticulture crops are drastically reduced as a result of air pollution. The severity of physiological disorders like black tip of mango is rising, due to increase in air pollutant likesulphur dioxide, ethylene, fluorides and carbon monooxide. High temperature also causes physiological disorder like girdle necrosis of mango, flower and fruit abscission and fruit cracking of citrus. Increase in temperature upto 31–32 °C enhances plant maturity in annual species, hence reducing the time it takes for developing fruits and suckers to absorb photosynthetic products [16]. High temperatures and moisture stress can make apples, apricots, and cherries more susceptible to sunburn and cracking [30]. The current area suited for the quality production of Dashehari and Alphonso mango types may vary with 0.7–1.0 °C of the temperature rises. The regions that are suitable for the development of red colour on guava may significantly decrease with a 0.2 °C rise in temperature [23]. Cold winter temperatures impact some tropical fruit crops, such as bananas, causing chilling injury and choke throat. Frost also have adverse impact on crops, Aonla, Phalsa, Ber, Moringa, Ficus species are adversely affected, moderately affected is the pomegranate, less affected are sapota and bael and unaffected is the date palm [41].

3.4 Vegetables

Air pollution damages many crops like carrot, turnip, soyabeans, potato, tomato, beet etc. Elevated CO_2 can also show positive effect on various vegetable crops. Hazra et al. [24] reported many reproductive abnormalities due to high temperature in chilli fruits like deterioration of the red colour development and in tomato poor pollen production, bud drop, dehiscence, abnormal flower development, and ovule abortion etc. [4]. If no specific techniques are adopted, Luck et al. [32] predicted a 16% drop in potato tuber yield in West Bengal by 2050. Temperatures above 21 °C significantly reduce potato tuber yield, while temperatures above 30 °C completely prohibit tuber formation [47]. Drought is a serious problem for potatoes. Reduced tuber yields can also be caused by moderate water stress [29]. Devi et al. [17] also reported a yield loss of 50–60% caused by drought in Chilli. A documented decrease in vegetable crop production due to the daily ozone concentration rising to 50 ppb has also been noted [40].

3.5 Plantation Crops and Flower Crops

Cashew experiences drying of flowers which results into reduction of yield when exposed to a temperature more than 34.4 °C and relative humidity lower than 20%. Jasmine is susceptible to low temperature and less than 19 °C inhibit flowering and ultimately reduces flower size whereas, orchids are affected by high temperature (>35 °C) which leads to bud drop and ultimately reduces flower yield [16].

3.6 Livestock, Poultry and Fishery Sectors

Variety of parameters that are linked to animal productivity, reproduction, health, and adaptability have been affected due to change in climatic condition. Erratic changes in weather directly impact animal output by 58% and reproduction by 63.3% [49]. Heat stress is common in dairy breeds than in meat types. Higher milk producing breeds are more vulnerable compare to the low milk yielding breeds due to their high metabolic heat generation [15]. The 1 °C rise in temperature will affect the fish distribution and its mortality [55]. An increase in temperature from 0.37 to 0.67 °C can alter the mating season of Indian main carps in fish hatcheries of West Bengal and Orissa from June to March.

4 Key Roles of Geospatial Technology in Climate Impact Assessment

Geospatial technology is a vital tool for climate impact assessment. It contains of multiple types of data that can be remotely gathered and analysed to determine the impact a change in weather, climate or regional geography has on socio-economic development. The effect of climate change on agricultural, forest, and water and livelihood security in India are of critical relevance to local and regional stakeholders and policymakers. Geographical study of climate changes and related repercussions in a spatially explicit manner is increasing relevance throughout the world to better address the issue. To begin with, Geospatial technologies are used to develop maps, models, and geographical information systems (GIS) that are critical for understanding climate impacts and helping to mitigate them. A key role of geospatial technology is to support climate impact assessment. In particular, new high-resolution terrestrial and space-based data sources are providing us with information that can be used to link environmental changes with other global environmental conditions like atmospheric circulation or water availability (e.g., evapotranspiration). However, it is important to understand how specific spatial layers—such as soil data or vegetation/vegetation cover—contribute to these models' performance. Apart from multivariate regression model and agro-climatic indices, the inclusion of satellite remote sensing, GIS and crop simulation modelling have enhanced the opportunity to study the and analyse the climate change impact in agricultural system.

4.1 Geographical Information System

It is an information system that involves gathering, storing, manipulating, analyzing and retrieving geospatial data. Many agricultural issues, such as agro-climatic risk assessment and agronomic decision-making, can be solved spatially with the help of GIS. The GIS has seen broad usage in land suitability classification, demarcation of watershed, and agro-ecological classification in the presence of varying degrees of terrain [31, 37]. Agro-climatic indices are generally employed as proxies to quantify regional or national crop development and present a complete picture of climate change. Temperature, precipitation, potential evaporation etc. are some of the important meteorological parameters which are used either single or in combination to build the agro-climatic indices. The International Institute for Applied Systems Analysis (IIASA) together with the United Nations Food and Agricultural Organization (FAO) developed a methodology and database, which is able to map accumulated temperature, moisture index, length of growing period, chilling unit accumulation, and other major agro-climatic indices using GIS environment [36].

5 Impact Assessment of Climate Change Using Satellite Remote Sensing

The use of satellite remote sensing technology as a tool to determine the impact of climate change has been considered rather limited even though satellites provide high spatial and temporal resolution observations over many years. Here we demonstrate that by combining satellite observations from sensors measuring atmospheric constituents with ground-based mapping of vegetation dynamics, remote sensing can be used for assessing the impacts of climate change on vegetation and ecosystem services in tropical regions. We found high agreement between satellite data and ground-based measurements for drought indicators, such as canopy decline rates and leaf area index values, as well as crop yield functions, particularly during the dry season (June–October). Area burned data exhibited high correlation with satellite remote sensing for two indices suggesting wildfire activity is influenced by weather conditions. There was also a significant positive relationship between canopy cover and land use efficiency suggesting that conversion of forested lands to other land uses may be more intensive in those areas where there is both low rainfall and soil fertility potential due to anthropogenic factors. To evaluate the active processes of the climate system and to enhance the climate projections, satellite data is playing an important tool along with climate models. Satellite data also helps to enhance

Atmospheric ECV	Oceanic ECV	Terrestrial ECV
• Wind speed and direction, CO_2 and O_3 • Radiation budget, wind speed and direction, water vapour, cloud properties and aerosol properties • Precipitation, upper air temperature	• Ocean salinity • SST, sea-ice extent • Sea level • Ocean colour, sea state	• Biomass, glacier and ice caps • Land cover, fire disturbance • Albedo, lakes (water levels and areas) • fAPAR LAI, soil moisture • Snow cover

Fig. 2 Essential climate variables retrieved from satellite observation

meteorological reanalysis outputs, which are the major inputs for climate change research. According to Yang et al. [57], essential climatic variables (ECVs) which are significantly dependent on satellite data are mentioned in Fig. 2.

Data from various satellites has been frequently employed to develop different strategies from climate change mitigation to adaptation. Satellite remote sensing is particularly useful for monitoring the earth's surface over large areas and in a consistent way. This allows us to better understand how our climate system works, as well as its changes over time.

A significant heat reservoir, the seas absorb and release heat in response to climatic changes. Furthermore, the atmospheric processes that generate wind and waves have a direct impact on the ocean's surface layer. As a result, variations in sea surface temperature (SST) can provide light on important climate system components including El Nio occurrences and tropical cyclone activity. The Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), TRMM Microwave Imager (TMI), Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E), Wind SAT, these sensors on different satellites allows us to monitor the SST worldwide (Fig. 3). According to Gnanaseelan et al. [22] and Beal et al. [8] the Indian Ocean is one of the world's fastest-warming ocean basins. According to Roxy et al. [43], during the period 1951–2015, the worldwide average increase in SST was 0.7 °C (0.11 °C/decade), while the Indian ocean SST increased by about 1.0 °C (0.15 °C/decade) (high confidence level). Satellite data also reveals a trend of unequal warming though out the ocean surface.

Romshoo et al. [42] utilised satellite data from1980 to2018 to assess the glacier health in the Kashmir Valley, which is crucial to understand the long-term sustainability of rivers that originate in the area. From the 1980 satellite image, 147 glaciers were mapped, 72% of the glaciers had an area of less than 3 km^2 and the bulk of them (123) have a size of less than 1 km^2.The glaciers have shrunk by 28.82% from 1980 to 2018. They concluded that rising temperatures and a decrease in snowfall have caused glacier retreat, resulting in stream flow depletion, which, if prolonged, would have a negative impact on the region's economy. To assess the effect of natural variations in

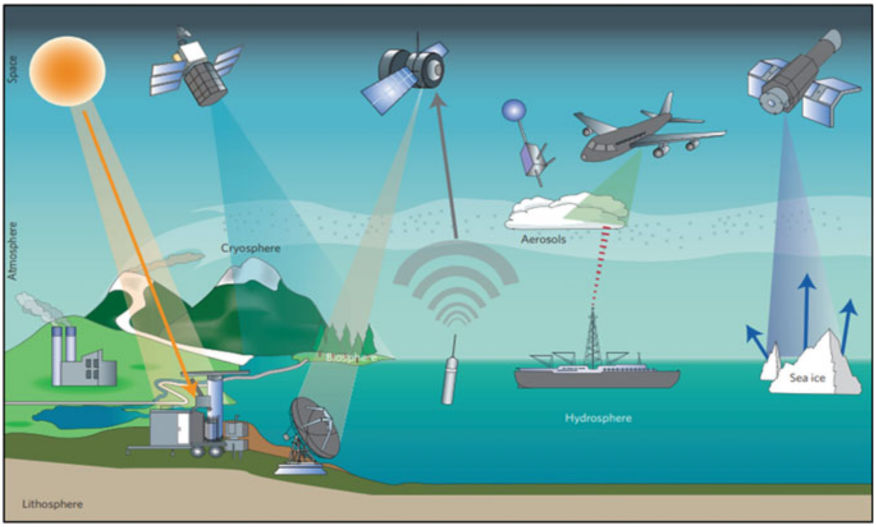

Fig. 3 Various remote sensing platforms, including planes, boats, and Argofloats

solar irradiation in modern climate change, researchers have examined the total solar irradiance (TSI). According to the spectrum irradiance monitor of SOURCE satellite, UV radiation has fallen four to six times more than model projections predicted across the solar magnetic energy cycle. This decrease is largely offset by an increase in visible-wavelength radiation. Aerosols, which are microscopic particles in the atmosphere, can chill the atmosphere, offsetting the warming impacts of GHG by altering both cloud precipitation processes and atmospheric radiation. Satellite data of aerosol-induced direct and indirect climate forcing offer climate models with independent comparisons. The direct radiative forcing by anthropogenic aerosols is computed by integrating satellite data of the radiation budget and AOD. The connections between cloud, aerosols, and precipitation are also better known with satellite remote sensing monitoring. The creation of ice crystals in supercooled clouds is enhanced by dust particles transferred to the cold cloud layer, according to data from cloud-aerosol LIDAR. Lower cloud albedo also means less solar radiation reflection and cooling effects [12].

6 Impact Assessment of Climate Change Using Simulation Modelling

Crop models appear to be a useful tool for studying and calculating the impact of climate change since they allow us to link various climate factors as well as crop development processes that are directly influenced by changing climate condition. In 2002, Aggarwal and Mall investigated climate change and rice yields in a variety of Indian agro-environments. They discovered that without CO_2 fertilisation, an increase of temperature by 1 °C in the north, west, east, and south reduces grain yield of rice by 5, 8, 5, and 7%, respectively. If the temperature is raised by 1 °C, yields are lowered by 10–16% in various parts of India, whereas an increase of 5 °C can reduce the yields by 21–31%. Aggarwal and Mall [2] observed that grain yields increased by 28–35% as atmospheric CO_2 concentrations increased from 350 to 700 ppm. If the temperature was increased by 1, 2, 3, 4, 5 °C at 350 ppm of CO_2 concentration, there was a change of –5, –12, –21, –25 and –31% in grain production of rice, but at 550 ppm yield changes were 12, 7, 1, –5 and –11% respectively. Jalota et al. [28] conducted a location specific climate change studies in a rice–wheat cropping system. They concluded that rainfall and temperature would increase in the mid-century (MC) and end-of-century (EC), but projected crop yields would decline due to shortening of crop duration. Delaying of rice transplanting and wheat seeding by 15–21 days could be the optimum adaptation strategy that can be followed in MC and EC to cope up with changing climate conditions. Jalota et al. [27] assessed the climate change impact in a rice–wheat cropping system by using CropSyst model. They predicted that growth period of the crop will be declining in near future which ultimately reduce the crop yield in long term. Increases in maximum temperature reduced yield more than decreases in minimum temperature. Future rainfall increases would decrease the need for crop irrigation water, but they wouldn't make up for the negative consequences of temperature increases. Dar et al. [13] predicted a decrease in rice crop irrigation requirements and a boost in wheat crop irrigation requirements. The model also forecasted future agricultural output declines due to a shortening of the growth period as a result of rising temperatures.

Dubey and Sharma [20] simulated the yield of Wheat, Barley and Maize from 1981 to 2010, in Banas basin of Rajasthan, then compared the predicted yield with observed yield data. They have found an increasing trend of crop yields for all three crops from 2021 to 2050. Boote et al. [10] used the DSSAT crop simulation model for peanut, soybean, dry bean, chickpea, sorghum, and millet to simulate yield sensitivity to increased temperature. The crop biomass was under represented by the CROPGROW-dry bean model, despite simulated biomass being zero at 35 °C. The CROPGRO-Peanut model, as modified by Vara Prasad et al. [53], was employed in this research, and no further modifications were required for that study region. At 40 °C, simulated biomass was zero, indicating that it was more heat resistant than dried bean. The CROPGRO-Chickpea model was recalibrated and parameterized using extensive growth and yield data on chickpea provided by ICRISAT scientists for several sites. When the mean temperature climbed from 26 to 35 °C, they built a function that enabled them reproduce the yield loss from optimal to zero.

Chandran et al. [11] assessed the impact of predicted climate on the performance of a rice–wheat–groundnut cropping sequence in Mohanpur, India, during end and mid-century of RCP4.5 and RCP8.5 scenarios. Results showed that all four future scenarios predicted a significant decline near about 4–17 days in crop duration for rice and 1–16 days for wheat. The duration of groundnut, on the other hand, rose by 1–4 days. For all three crops, increasing trends in biomass was observed when CO_2 levels were raised. Rice yields tend to increase during future periods of elevated

CO_2, although wheat and groundnut experienced an yield reduction in all future scenarios. Poonia et al. [38] studied the impact of climate change under RCP 4.5 and RCP 8.5 scenarios on crop water dynamics in eastern Himalayan region, Sikkim. Climate datasets are collected for the future period (2021–2099) from CORDEX's four climate models namely ACCESS1-0, CCSM4, CNRM-CM5, and MPI-ESM-LR. In comparison to the baseline era, the study's findings imply an increase in the crop water requirement for rice by 8% and wheat by 39% towards the end of the twenty-first. In the case of maize, crop irrigation requirement has escalated in the majority of cases since the end of the twenty-first century. Dubey et al. [19] used InfoCrop model to determine the effects of terminal heat stress on wheat production and adapting strategies. In the year 2050 there will be decrease in wheat yield by 11.1% due to terminal heat stress. Advancement of the sowing date, an additional nitrogen dose, and watering during the seed setting stage were proven effective methods to minimize yield loss. In the year 2050, adaptation of above mentioned methods will help reducing the heat stress impact by 9%.

7 Impact Assessment of Climate Change Through Integration of Crop Models and Geospatial Technology

The integration of Crop models and geographic information systems (GIS) has showed great potential in solving a variety of environmental and agricultural decision-making issues. According to Subash and Mohan [50], several crop models, such as the DSSAT models, EPIC, and WOFOST, are now coupled to GIS environment and extensively employed in field applications. Additionally, by combining crop growth models and satellite data in a GIS, depending on researchers' interpretation, may anticipate agricultural production and aid in risk management, problem-solving, and decision-making. In India, the wheat growth simulation model (WTGROWS) and GIS were used to develop a basic crop growth monitoring system (CGMS) for monitoring wheat growth and yield for Haryana [46]. Tripathy et al. [52] simulated wheat grain yield for Punjab (India) by assimilating remote sensing inputs in the mechanistic WOFOST model. In order to analyse the degree of changes in rice, wheat, and maize crop production, Patel et al. [36] employed a GIS-based EPIC model in Dehradun (India). The simulation model findings demonstrated considerable spatial variability in estimated crop yields during three different future climate change scenarios and the baseline. Even raising CO_2 levels would not be enough to compensate for the losses experienced due to the significant rise in temperature in the 2080s, according to the findings. The decline in crop yields (percent) without CO_2 fertilisation in the 2080s was found to be in the range of 14, 19, and 42% for maize, rice, and wheat, respectively.

7.1 Key Limitations of Geospatial and Modelling Approach

Concerns have been raised about satellite data's reliability for monitoring and understanding of climate change. Climate change research required calibrated/validated datasets that are consistent through time, as well as accurate sampling in both time and space. On the other hand, satellite image data typically includes uncertainties because of sensor biases, retrieval methods, and variations across satellite missions employing the same sensors. Understanding these limitations in depth is necessary for the use of satellite observations in climate change research. Model construction necessitates specialised training. It is a skill that is developed over time and through practise. It might be difficult to comprehend simulation findings at times, and it can also be difficult to simulate an exact thing. Any flawed model may produce erroneous results when used with confidence. Because simulation does not supply answers on its own, the decision-maker must provide all information (depending on the model) regarding the limitations and conditions for evaluation.

8 Conclusions

Agriculture is extremely vulnerable to weather fluctuations, both short-term and long-term, as well as seasonal, yearly, and long-term climatic variations. It will eventually have an impact on the availability, accessibility, and stability of the food supply, threatening the nation's food security. In the face of changing climate, for managing agriculture and its resources accurate crop yield estimation and forecasting at regional and global scales is critical. The growth and development of crops at a field scale under diverse biotic and abiotic conditions may be accurately predicted and simulated using crop growth simulation models. Crop monitoring over a vast area can also benefit from satellite remote sensing. On a local and global level, using data assimilation to combine remote sensing data with crop models can improve the precision of crop model yield predictions. The use of remote sensing satellite data in coupling with a crop-growth simulation model and a data assimilation approach is proving to be a viable monitoring technique for crop development and grain production as it fixes the problems and enhances the advantages of earlier work. Furthermore, incorporating remote-sensing data into a data assimilation method could reduce crop growth model uncertainty and make sure that predicted values are closer to the observed ones.

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