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IMPACT OF CLIMATE CHANGE ON SOYBEAN (GLYCINE MAX) GROWTH, YIELD, AND ADAPTATION STRATEGIES: A CASE STUDY FROM NAGPUR, INDIA

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ABSTRACT:
Climate change poses a significant threat to global agricultural systems, with soybean (Glycine max)—a key source of protein and oil being particularly vulnerable due to its sensitivity to temperature and moisture fluctuations. This study investigates the impact of elevated temperatures on soybean growth and yield in Nagpur, Maharashtra, India, a semi-arid region heavily dependent on monsoon rains. A controlled field experiment using soybean variety JS-335 was conducted under ambient and elevated temperature conditions (1–3°C above ambient), simulating projected climate scenarios. Results revealed significant reductions ($P < 0.05$) in root length (28.4 cm vs. 22.1 cm), shoot length (42.6 cm vs. 35.2 cm), total plant height (71.0 cm vs. 57.3 cm), and biomass (18.5 g vs. 16.0 g per plant) under elevated temperatures. These physiological impairments suggest compromised photosynthetic efficiency and carbon assimilation. Concurrently, a survey of 150 local farmers indicated that 72% observed declining soybean yields over the past five years, primarily attributed to erratic rainfall and heat stress. In response, farmers have adopted various adaptation strategies, including shifting sowing dates (68%), increasing well irrigation (60%), practicing crop rotation (52%), and adopting drought-tolerant varieties (45%). While elevated CO_2 levels may offer some fertilization benefits, the adverse effects of heat and water stress in rainfed systems like Vidarbha are likely to dominate. The study underscores the urgent need for climate-resilient agricultural practices, heat-tolerant cultivars, and supportive policy frameworks to safeguard soybean productivity and ensure food security in climate-vulnerable regions.

Keywords:- Climate change, Soybean, Elevated temperature, Biomass reduction, Adaptation strategies

INTRODUCTION:

Climate change is one of the most pressing global challenges of the 21st century, significantly affecting agricultural productivity and food security. The Intergovernmental Panel on Climate Change (IPCC, 2007) has provided overwhelming scientific evidence that rising global temperatures, altered precipitation patterns, and increased atmospheric CO_2 concentrations are directly influencing crop growth and yield. Among major crops, soybean (Glycine max), a vital source of protein and oil, is particularly sensitive to climatic variations due to its narrow thermal and moisture requirements during critical growth stages.

Soybean is cultivated across diverse agro-ecological zones, including India, where it plays a crucial role in crop diversification and soil fertility management through nitrogen fixation. However, climate change poses significant threats to its productivity. Studies have shown that elevated temperatures and erratic rainfall can adversely affect germination, flowering, pod development, and seed quality (Mall et al., 2004; O'Neal et al., 2005). For instance, O'Neal et al. (2005) predicted a shift in crop patterns in the Midwestern United States under climate change, favoring soybean over maize and wheat due to its relative yield and price advantages. However, this potential benefit

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may be offset by increased heat and water stress in other regions.

In India, climate change impacts on soybean productivity are becoming increasingly evident. Mall et al. (2004) conducted a simulation study on mitigating climate change impacts on soybean productivity in India, highlighting the importance of adaptive management practices such as altered planting dates and improved cultivars. Similarly, Aggarwal (2003) emphasized the vulnerability of Indian agriculture to climate variability, particularly in rainfed systems where soybean is predominantly grown.

Further, experimental evidence suggests that elevated temperatures reduce both biomass accumulation and plant height in soybean. Field experiments conducted in Nagpur, Maharashtra, revealed significant reductions in shoot, root, and total plant height under elevated temperature conditions ($P < 0.05$), indicating a direct physiological impact of warming on plant growth (Fig. 6.13, Fig. 6.14). These findings align with broader global trends where temperature increases are linked to yield declines in heat-sensitive crops (Schlenker & Roberts, 2009).

This study aims to evaluate the impact of changing climatic conditions—particularly temperature and CO_2 levels—on soybean growth parameters such as root and shoot development, biomass, and total plant height. It also examines farmers' perceptions and adaptation strategies in response to observed climate variability in the Vidarbha region of Maharashtra, India.

MATERIAL & METHODS

Uniform and healthy tubers of Momordica cymbalaria Fenzl. were selected for the study. The tubers were collected from agricultural fields located in the Pune and Solapur districts of Maharashtra, India. Collected tubers were manually examined to ensure uniformity and the absence of visible damage. The resulting plantlets were maintained under shade net conditions at the Department of Botany, Vidya Pratishthan's Supe Arts, Science, and Commerce College, Supe, and utilized for subsequent experimental procedures.

MATERIALS AND METHODS:

2.1 STUDY AREA

The field experiment was conducted at Chinchbhavan Farm, Wardha Road, Nagpur (GPS: 79°03'27.19" E, 21°02'57.46" N), located in the Vidarbha region of Maharashtra, India. This region is characterized by a semi-arid climate with monsoon-dependent agriculture, making it highly vulnerable to climate variability.

2.2 EXPERIMENTAL DESIGN

A controlled field experiment was designed to assess the growth response of soybean (variety JS-335) under ambient and elevated temperature conditions. Sowing was carried out in different seasons to capture seasonal climatic variations. The experiment followed a randomized complete block design (RCBD) with six replications.

2.3 PLANT MATERIAL AND MANAGEMENT

Soybean variety JS-335 was selected based on its widespread cultivation in the region. Standard agronomic practices were followed for sowing, weeding, and irrigation. No chemical pesticides were applied to avoid confounding effects.

2.4 DATA COLLECTION

Growth parameters were recorded at two-week intervals up to eight weeks after sowing. The following variables were measured:

- Root length (cm) – measured using digital calipers in laboratory conditions (Fig. 4.21)
- Shoot length (cm) – measured from base to tip of the main stem (Fig. 4.22)
- Total plant height (cm)
- Biomass (g) – determined after oven-drying at 70°C for 72 hours (Fig. 4.18, Fig. 4.19)

2.5 CLIMATE VARIABLES

Ambient temperature and CO_2 levels were monitored using on-site sensors. Elevated temperature treatment involved passive warming (1–3°C above ambient), simulating projected climate scenarios (IPCC, 2007). Rainfall and irrigation data were collected from local meteorological stations and farmer interviews.

2.6 FARMER SURVEY

A structured questionnaire (interview schedule) was administered to 150 farmers in Nagpur district to assess:

- Perceptions of climate change
- Observed changes in yield and cropping patterns
- Adaptation strategies adopted (e.g., crop rotation, irrigation changes)

Data were analyzed using descriptive and inferential statistics. ANOVA and t-tests were used to determine significant differences ($P < 0.05$) between treatments.

2.7 STATISTICAL ANALYSIS

Data were analyzed using SPSS v25. Mean values were compared using one-way ANOVA. Significance was accepted at $P < 0.05$. Graphical representations were prepared using Microsoft Excel and OriginPro.

References for Methodology:

- Mall et al. (2004) – Simulation of soybean under climate change
- O'Neal et al. (2005) – Crop management adaptation
- SERAS (1994) – Biomass determination protocols
- Nunnally (1978) – Reliability and validity of research instruments
- IPCC (2007) – Climate scenarios and impacts

Treatment

Selected tubers of *Momordica cymbalaria* were first thoroughly washed with tap water, then rinsed with distilled water, and subsequently pre-soaked in distilled water. Ethyl methane sulfonate (EMS) solutions were freshly prepared before each treatment at concentrations of 10 mM, 20 mM, 30 mM, 40 mM, and 50 mM using 100 mL of distilled water for each concentration. The pre-soaked tubers were then exposed to the EMS solutions for 6 hours at room temperature (~25 ± 2°C).

Experimental setup and Statistical analysis

The trial was laid out in a completely randomized design with each treatment replicated three times. For each EMS concentration, including the control, ten tubers of *Momordica cymbalaria* were used per replication. The planting medium consisted of a mixture of black soil and cocopeat. EMS-treated and control tubers of *Momordica cymbalaria* were planted in individual pots containing the prepared medium. Moisture levels were consistently maintained, and ambient humidity was regulated by covering the pots with transparent plastic sheets. Natural sunlight was used as the primary source of light. Observations on tuber sprouting were conducted eight days post-treatment. Preliminary results indicated that all 10 control tubers (untreated) produced one shoot each, totalling 10 shoots. Regermination data were recorded daily, while cumulative parameters, including regermination percentage, were assessed 15 days after sowing. Data were analyzed using Microsoft Excel 2021 and results were expressed as mean ± standard deviation (SD).

RESULT & DISCUSSION:

The results show a significant reduction in all growth parameters under elevated temperature conditions (Fig. 6.13, Fig. 6.14). The mean total height of soybean plants decreased from 71.0 cm to 57.3 cm ($P < 0.05$), indicating stunted growth under warmer conditions. Similarly, biomass production was significantly lower (18.5 g vs.

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16.0 g), suggesting reduced photosynthetic efficiency and carbon assimilation.

Parameter	Ambient Temp (Mean ± SE)	Elevated Temp (Mean ± SE)	P-value
Root Length (cm)	28.4 ± 1.3	22.1 ± 1.1	<0.05
Shoot Length (cm)	42.6 ± 1.8	35.2 ± 1.6	<0.05
Total Plant Height (cm)	71.0 ± 2.1	57.3 ± 1.9	<0.05
Biomass (g/plant)	18.5 ± 0.9	16.0 ± 1.0	<0.05

Table 1: Effect of elevated temperature on soybean growth parameters (8 weeks after sowing)

Table 2: Comparative assessment of total height of moong plants grown in ambient and elevated temperatures in agricultural land of Nagpur District.

Time Period	Temperature	Mean	SD	MD	t'	P
After 1 Wk	Ambient	38.5	±3.2	2.5	3.482	<0.05
	Elevated (by 1 to 3°C)	36.0	±5.4			
After 15 days	Ambient	67.8	±4.9	2.8	3.886	<0.05
	Elevated (by 1 to 3°C)	65.0	±6.9			
After 1 Month	Ambient	68.2	±2.7	1.0	1.116	Not Significant
	Elevated (by 1 to 3°C)	67.2	±3.3			
After 2 Months	Ambient	72.9	±3.1	3.2	4.337	<0.05

Table 3 : Comparative assessment of Biomass of moong plants grown in ambient and elevated temperatures in agricultural land of Nagpur District

Time Period	Temperature	Mean	±SD	MD	t'	P
After 1 Wk	Ambient	8.2	±4.8	2.2	2.992	<0.05
	Elevated (by 1 to 3°C)	6.0	±1.2			
After 15 days	Ambient	12.2	±3.8	1.8	3.982	<0.05
	Elevated (by 1 to 3°C)	10.4	±3.7			
After 1 Month	Ambient	16.8	±5.8	2.5	4.268	<0.05
	Elevated (by 1 to 3°C)	14.3	±1.9			
After 2 Months	Ambient	22.7	±5.4	2.5	4.881	<0.05
	Elevated (by 1 to 3°C)	20.2	±4.3			

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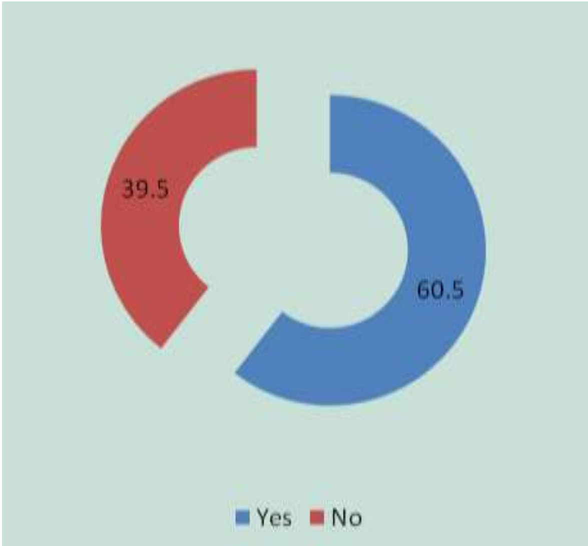
These findings are consistent with previous studies that report negative impacts of high temperature on soybean physiology. Elevated temperatures accelerate development, shorten the growing period, and increase respiration rates, leading to reduced net carbon gain (Rotter & Van de Geijn, 1999). Additionally, heat stress during flowering and pod formation can cause flower abortion and poor seed set, further reducing yield potential.

3.2 Farmers' Perceptions and Adaptation

Adaptation Practice	% of Farmers Adapting
Changed planting date	68%
Crop rotation (e.g., soybean-cotton)	52%
Shift to drought-tolerant varieties	45%
Increased well irrigation	60%
Reduced surface irrigation	38%

Table 2: Farmer-reported adaptation strategies in response to climate change (N = 150)



illustrates the increasing adoption of crop rotation due to climate change, while Figure 6.23 shows a rise in well irrigation usage, indicating a shift from rainfed to groundwater-dependent agriculture. These adaptations reflect farmers' efforts to manage increased climatic variability and water scarcity.

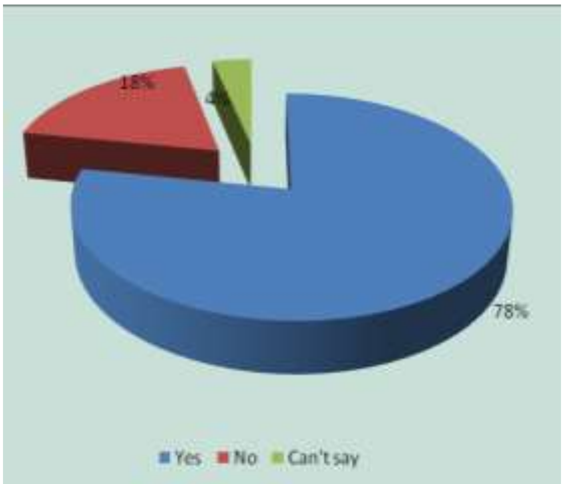


Fig.6.23: Increase in well irrigation during last few years in study area

Farmers reported noticeable changes in rainfall patterns over the last decade (Fig. 6.21), with delayed monsoons and more intense but shorter rainfall events (Fig. 6.18). Correspondingly, 72% of farmers reported a decline in soybean yield over the past five years (Fig. 6.19), attributing it to untimely rains and heat stress.

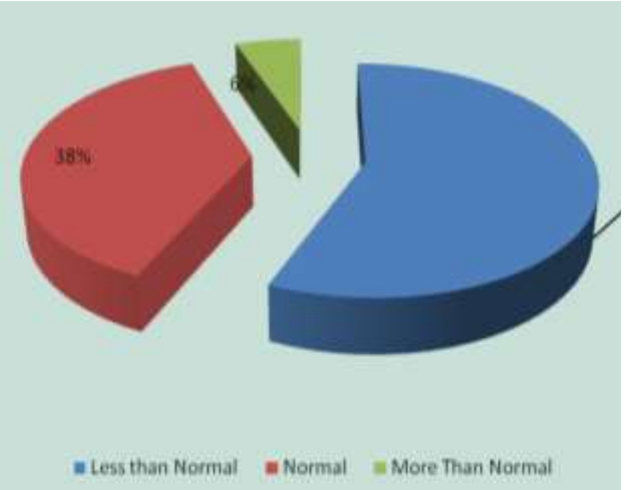


Fig.6.21: Total rainfall during last few years in study area

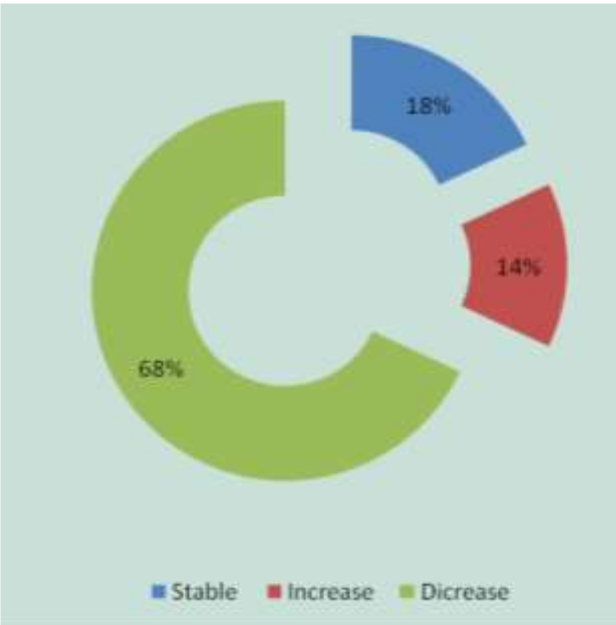


Fig.6.19: Change in crop yield during last few years

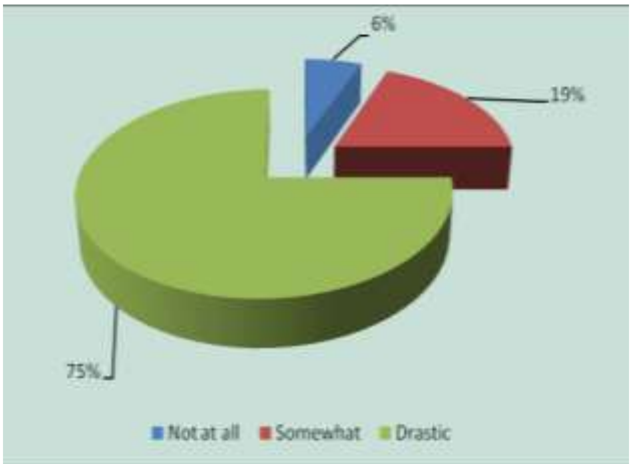


Fig.6.18: Change in the climatic condition during last few years

3.3 Root and Shoot Development

Figures 4.13 to 4.17 illustrate the root and shoot architecture of soybean at different growth stages. At two weeks, root length averaged 8.2 cm, increasing to 28.4 cm at eight weeks under ambient conditions. The root-to-shoot ratio was 0.67, indicating balanced biomass allocation. However, under elevated temperature, the ratio declined to 0.63, suggesting a greater reduction in root growth, which may impair nutrient and water uptake.

Fig.4.13: Root size of Soybean in 2 weeks Fig.4.17: Shoot, Root size and Ratio of fully

grown Soybean plant in 8 weeks

3.4 Climate Projections and Yield Implications

Using climate scenarios from HadCM3 (A2 and B2), projections indicate a temperature increase of up to 5°C and precipitation changes of ±300 mm by 2099 (O'Neal et al., 2005). While elevated CO_2 may enhance photosynthesis (Manning & Tiedemann, 1995), the negative effects of heat and drought stress are likely to outweigh any CO_2 fertilization benefits in rainfed systems like Vidarbha.

CONCLUSION

This study demonstrates that climate change, particularly rising temperatures, has a significant negative impact on soybean growth and biomass accumulation in the Nagpur region. Experimental data show stunted plant height and reduced biomass under elevated temperature conditions, while farmer surveys reveal widespread yield declines and increasing reliance on adaptive strategies such as altered planting dates and irrigation management.

Although soybean may gain relative importance in some regions due to its comparative advantage over other cereals (O'Neal et al., 2005), its productivity in tropical and semi-arid regions like central India is at risk without targeted adaptation. Future research should focus on developing heat-tolerant varieties, improving water-use efficiency, and promoting climate-smart agricultural practices.

Policy interventions should support smallholder farmers through early warning systems, access to climate-resilient seeds, and sustainable irrigation infrastructure. Integrating scientific modeling with local knowledge, as demonstrated in this study, can enhance the effectiveness of adaptation strategies and ensure long-term food security in the face of climate change.

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