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Impact of Environmental and Technological Factors on Cotton Yield in Dhule District

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Abstract
Cotton, often referred to as "White Gold," plays a critical role in India's economy, particularly in regions like Dhule district, Maharashtra, where it shapes the socio-economic and agricultural landscape. This study examines the interplay between environmental and technological factors affecting cotton yield in the district. By leveraging geospatial analysis and field-level observations, the research highlights how agro-climatic conditions such as rainfall variability, temperature fluctuations, and soil characteristics impact cotton productivity. The study also evaluates the role of technological advancements, including the adoption of Bt cotton, which has contributed to significant yield improvements despite challenges such as pest resistance and high input costs. The findings underscore the necessity for integrated approaches combining precision agriculture, sustainable water management, and farmer education to address environmental adversities and enhance cotton yield. This work provides actionable insights for policymakers to promote resilience and sustainability in cotton farming.

Keywords: Environmental Factors, Technological Advancements, Agro-Climatic Conditions, Geospatial Analysis, Sustainable Agriculture.

Introduction

Cotton, often referred to as "White Gold," holds a significant place in the global economy as a vital cash crop. India, being one of the world's largest producers, accounts for 25% of global cotton production (Jans et al.2021). The cultivation of cotton in India, especially in states like Maharashtra, has been a cornerstone of the agricultural and industrial sectors, offering employment to millions. Dhule district, located in the northwestern part of Maharashtra, represents a unique case where geographical, environmental, and technological factors interplay to influence cotton yield. Despite significant advancements, the region has faced challenges such as stagnant productivity and environmental adversities (Habiyaremye et al.2022). This study investigates the impact of environmental and technological factors on cotton yield in Dhule district, analyzing trends and exploring the implications of advancements like Bt cotton adoption. Within India, the Dhule District of Maharashtra holds a unique position, with cotton cultivation shaping the socio-economic and agricultural landscape. However, environmental and technological factors significantly influence cotton yield in this region. While environmental conditions such as climate, soil, and irrigation have always played a key role, recent technological advancements, including the introduction of Bt cotton, have transformed the productivity and practices of cotton farming (Lu et al., 2022). This research paper explores the impact of environmental and technological factors on cotton yield in Dhule District, focusing on agro-climatic conditions, spatial and temporal trends, and the integration of modern technology. By combining geospatial analysis with field-level observations, this study highlights the dynamic relationship between geography and technology in enhancing cotton productivity.

Aim and Objectives

The primary aim of this research is to evaluate the environmental and technological determinants affecting cotton yield in Dhule district. The objectives include:

1. Assessing the agro-climatic and economic conditions for cotton cultivation.
2. Analyzing the spatial and temporal patterns of cotton production and yield.
3. Evaluating the role of technological advancements, including the introduction of Bt cotton, in enhancing productivity.

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4. Identifying challenges faced by cotton farmers and providing actionable suggestions.

Study Area

Dhule District is located in the northwestern part of Maharashtra, between 20° 37' 39'' to 21° 38' 02'' N latitude and 73° 51' 02'' to 75° 12' 19'' E longitude, covering an area of 7,195 sq. km. The district is characterized by a semi-arid climate, with annual rainfall averaging 607 mm, and significant variation in temperature between seasons. The region's soil types include vertisols and alluvial plains, making it suitable for cotton cultivation.

Database and Methodology

The study utilizes both primary and secondary data. Secondary data sources include reports from the Maharashtra Department of Agriculture, meteorological data, and previous studies on cotton cultivation. Primary data were collected through surveys and interviews with cotton farmers across Dhule's tehsils, focusing on their practices, inputs, and challenges. The study area comprises Dhule, Shindkheda, Sakri, and Shirpur tehsils, characterized by diverse physiographic and agro-climatic conditions.

Spatial data analysis was conducted using Geographic Information System (ArcGIS Pro) tools to map trends in cotton cultivation, production, and yield. Statistical techniques, including trend analysis and correlation studies, were employed to evaluate the relationships between environmental variables (rainfall, temperature, soil type) and cotton yield. Temporal trends from 1966 to 2020 were analyzed to assess the impact of technological interventions such as Bt cotton.

Results and Discussion

Statistical Analysis

The statistical analysis revealed significant temporal and spatial variations in cotton yield in Dhule district. Data indicate that the introduction of Bt cotton in the early 2000s significantly increased production and yield. However, environmental factors, including erratic rainfall, high temperatures, and soil conditions, continue to pose challenges. The average annual rainfall of 607 mm, concentrated during the monsoon, often leads to uneven water distribution, affecting crop growth. Regression analysis between rainfall and yield highlighted a moderate positive correlation (R=0.67), indicating that consistent rainfall enhances productivity.

Technological advancements like the adoption of Bt cotton seeds and improved irrigation practices were found to mitigate some of the adverse impacts of environmental factors. Farmers using Bt cotton reported an average yield increase of 50% compared to traditional varieties. However, challenges such as pest resistance, high input costs, and inadequate irrigation facilities were recurrent themes in farmer interviews.

Environmental Profile and Agro-Climatic Conditions

The environmental profile of Dhule District plays a crucial role in determining cotton yield. The district's physiography comprises the Satpura mountain ranges, Galna Hills, and alluvial plains. These geographic features influence soil fertility, drainage patterns, and micro-climatic conditions.

- **Temperature:** Cotton thrives within a temperature range of 21°C to 30°C. In Dhule, the maximum temperature reaches 40.9°C in summer, creating heat stress, while winter temperatures as low as 17.8°C are conducive to flowering.
- **Rainfall:** Rainfall distribution is uneven, with the majority concentrated during the monsoon season (June to September). Insufficient or erratic rainfall often results in drought conditions, affecting crop growth.
- **Soil Types:** Vertisols dominate the district, offering good moisture retention but requiring proper management to avoid waterlogging. Alluvial soils in the plains support high cotton productivity.

Spatial Patterns of Cotton Cultivation

Cotton cultivation in Dhule district exhibits a distinct spatial distribution influenced by physiographic conditions. The alluvial plains in the central region, with fertile soils, account for the highest cotton acreage. In contrast, areas with Deccan basalt and shallow soils, such as the northern and southern regions, exhibit lower yields. GIS mapping of cotton yield patterns from 1990 to 2020

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reveals a gradual shift in cultivation areas, with an increasing preference for regions equipped with irrigation facilities. Geospatial analysis reveals significant spatial variations in cotton cultivation across the district's four tehsils: Dhule, Shindkheda, Sakri, and Shirpur. Cotton cultivation is most prevalent in the central and eastern parts of the district, where soil fertility and irrigation facilities are better (Zhu et al.2023).

Temporal Trends in Cotton Yield

The temporal analysis indicates a steady increase in cotton yield since the introduction of Bt cotton. From 1966-67 to 2019-20, the average yield rose from 33.33 kg/ha to 406.82 kg/ha. This increase can be attributed to technological interventions, including high-yielding varieties and better pest management. However, the analysis also highlights periods of stagnation during years of erratic rainfall or pest outbreaks. Temporal analysis indicates a steady increase in the area under cotton cultivation from 1966-67 to 2019-20, particularly after the introduction of Bt cotton. However, yield fluctuations are closely linked to climatic variability, especially monsoon rainfall.

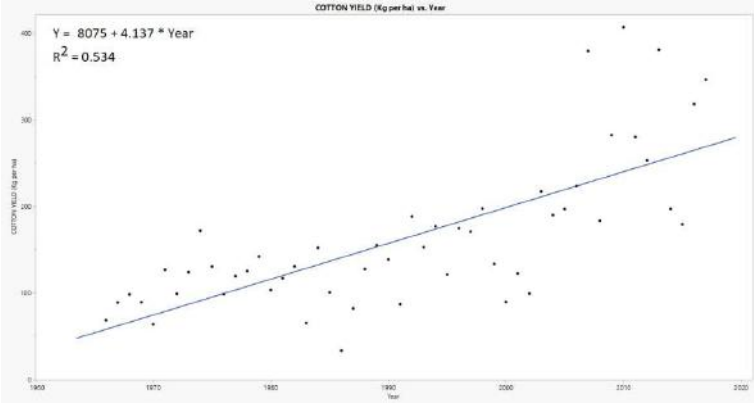

Figure 1 Trend of Cotton Yield in the Dhule District

Technological Interventions

The introduction of Bt cotton has revolutionized cotton farming in Dhule, reducing pest-related losses and increasing productivity. Survey results indicate that 80% of farmers have adopted Bt cotton, leading to reduced pesticide usage and higher economic returns. However, issues such as fake seeds, high input costs, and limited awareness about optimal practices were frequently reported. Technological advancements need to be supplemented with better extension services to ensure equitable benefits across the district (Narawade et al.2023).

Technological Advancements

The introduction of Bt cotton has significantly improved cotton yield in Dhule District. Bt cotton's resistance to bollworm pests has reduced pesticide use and increased profitability for farmers. Between 2003-04 and 2019-20, cotton yield in the district rose from 33.33 kg/ha to 406.82 kg/ha, reflecting the positive impact of this technology. Farmers adopting Bt cotton reported: Reduced expenditure on pesticides by 50%, Increased yield by 30-40% compared to non-Bt cotton; and Enhanced crop resilience to pest attacks. Despite these benefits, challenges persist, including high seed costs and dependency on external inputs. Adoption of integrated pest management (IPM) practices and organic farming techniques could complement technological advancements.

Environmental Factors Affecting Cotton Yield

Cotton yield is determined by a complex interplay of factors, both environmental and technological. In Dhule district, environmental factors are major determinants of cotton yield (Mahajan et al.2024). Rainfed agriculture is dependent on climatic factors. Hence, variations in yield might be due to fluctuations in climate parameters such as rainfall. Temperature during the growing season is also a key factor. Though cotton is a hardy and versatile crop with respect to its temperature adaptation, temperature rise or temperature fluctuations are not good for the crop. Cotton grows well under temperatures ranging from 23 to 27°C, and higher temperatures in many

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cases increase respiration, which ultimately lowers production. (Snider et al.2022) Continuous heavy rainfall is one of the major challenges in Dhule district; nipple dropping, boll shedding, and boll rot are frequently observed in farmers' fields. Rainfall variability and uncertainty are major problems. During 2019, there was a heavy spell of rain in June in the whole of the Khandesh region.

The black cotton and regur soil are the major types of soil in the Dhule district in general. Soil texture, soil pH, and the presence of nutrients are the key factors determining cotton yield (Dilip, 2024). There is a direct relationship between soil texture and cotton yield, but also an indirect one, as the soil texture needs to be corrected by adding various additives, which necessitates incurring more costs. In Khandesh, more costs and inputs are needed to increase the pH, i.e., removing the very fertile black cotton soil and adding agricultural lime, which would lower the yield, as indicated by our models. The shift towards sugarcane cultivation on a large area cannot be profitable, as indicated by the negative coefficient. The interaction between soil texture and rainfall is also important for the calculation of yield (Qin et al.2021). Several studies have also stated the impact of soil texture on the yield of various crops like soybean, sugarcane, and cotton. In eastern Uttar Pradesh, it has been observed that heavy textured soils give higher yields than medium and light textured soils due to better moisture retention capacity and nutrient availability of the heavy textured soils.

Environmental Challenges

Environmental factors remain critical in determining cotton yield. High temperatures during the flowering stage and inconsistent rainfall patterns were identified as major constraints. Soil analysis revealed that vertisols, predominant in the region, offer good water retention but require proper management to prevent salinity. Farmers practicing crop rotation and integrated nutrient management reported better yields, emphasizing the need for sustainable agricultural practices.

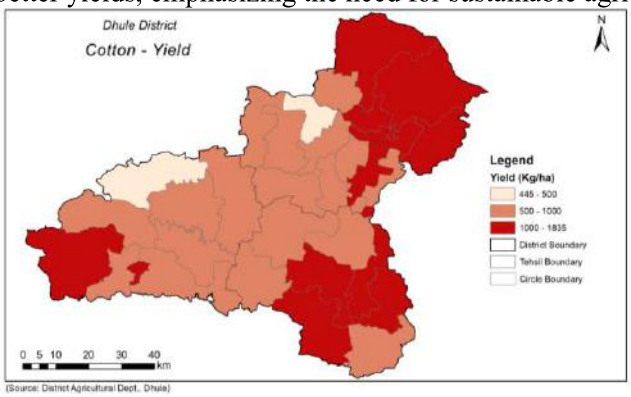

Figure 2 Spatial distribution of Cotton Yield in the Dhule District

Conclusion

The study underscores the interplay between environmental and technological factors in shaping cotton productivity in Dhule district. While technological advancements like Bt cotton have significantly improved yields, environmental challenges persist. Addressing issues such as water scarcity, soil management, and farmer education is essential to sustain productivity gains. Policies promoting affordable irrigation technologies, quality seed distribution, and farmer training programs can enhance resilience against climatic adversities. Advancements such as Bt cotton have revolutionized productivity, the region's semi-arid climate and irrigation deficits remain significant challenges. Policymakers must prioritize sustainable agricultural practices, including water resource management and farmer education programs, to enhance cotton production sustainably. Future research should focus on integrating remote sensing data with real-time weather monitoring to develop precision agriculture techniques. Additionally, promoting eco-friendly farming practices and diversifying cropping systems can further improve the resilience and profitability of cotton farming in Dhule District.

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