

EFFECTS OF CLIMATE-SENSITIVE FARMING METHODS ON INCREASING COTTON YIELD*

ВЛИЯНИЕ КЛИМАТИЧЕСКИ ОПТИМИЗИРОВАННЫХ МЕТОДОВ ВЕДЕНИЯ СЕЛЬСКОГО ХОЗЯЙСТВА НА ПОВЫШЕНИЕ УРОЖАЙНОСТИ ХЛОПКА

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The article assesses the impact of climate change on the development of the textile industry in the Republic of Kazakhstan. The topic is relevant because the temperature on the entire planet continues to rise, and weather conditions affect agriculture, and in particular the cultivation of cotton, the main material for textiles. This study calculates the Higg Material Sustainability Index (Higg MSI) and the Higg Product Module (Higg PM) to assess the impact of cotton on the environment and production, which provides a more structured analysis. A decrease in the yield of crops such as cotton when grown in various adverse climatic conditions is becoming a serious problem for the textile industry. The study identified the impact of temperature and precipitation on cotton yields and analyzed possible options for state support for agriculture. Based on modeling and scenario analysis, it was found that with high state support and innovation, the adverse effects of weather conditions can be offset, but at extreme temperatures, yields will be low. Based on the study results, recommendations were made, regarding the need to introduce innovations and sustainable technologies, develop state support programs and international cooperation to ensure the continued competitiveness of textile production in Kazakhstan.

В статье оценено влияние изменения климата на развитие текстильной промышленности Республики Казахстан. Тема актуальна, поскольку температура на всей планете продолжает повышаться, а погодные условия влияют на сельское хозяйство, и в частности на выращивание хлопка – основного материала для получения текстиля. В этом исследовании проведены расчеты индекса устойчивости материалов Higg (Higg MSI) и модуля продуктов Higg (Higg PM) для оценки воздействия хлопка на окружающую среду и производство, что обеспечивает более структурированный анализ. Снижение урожайности таких культур, как хлопок, при выращивании в различных неблагоприятных климатических условиях становится серьезной проблемой для текстильной промышленности. В ходе исследо-

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вания выявлено влияние температуры и осадков на урожайность хлопка, проанализированы возможные варианты государственной поддержки сельского хозяйства. На основе моделирования и анализа сценариев установлено, что при наличии высокой государственной поддержки и инноваций неблагоприятные последствия погодных условий могут быть компенсированы, однако при экстремальных температурах урожайность будет низкой. По результатам исследования даны рекомендации, касающиеся необходимости внедрения инноваций и устойчивых технологий, разработки программ государственной поддержки и международного сотрудничества для обеспечения постоянной конкурентоспособности текстильного производства в Казахстане.

Keywords: climate change, textile industry, raw materials, cotton production.

Ключевые слова: изменение климата, текстильная промышленность, сырье, производство хлопка.

Introduction

The textile and clothing industry of Kazakhstan is an important source of raw materials for further distribution in the country's garment industry. However, changes in climatic conditions, such as increasing temperatures and irregular precipitation, and insufficient technological equipment also pose a threat to the industry. According to Novikova Zh. A. et al., the importance of the development of the textile industry is explained by the need to update the industry, which is experiencing certain problems with the quality of raw materials and the level of R&D. The purpose of this work is to study the impact of climate change on the yield of raw materials most needed for textile production, and to determine methods for adapting the industry, which largely depends on such yields [1].

Yusupov's works state that the changing climatic situation in the Turkestan region critically affects cotton yields, particularly in terms of quality and quantity. His findings demonstrate that yield per hectare varies significantly depending on climatic conditions and cotton varieties, reaffirming earlier research on the essential role of temperature and precipitation in the industry's stability. The authors' conclusions show that the yield per hectare differs depending on climatic conditions depending on cotton varieties, which confirms the earlier conclusions of observers about the importance of assessing the influ-

ence of temperature and precipitation factors on the development of the textile industry as a whole [2].

In this study, the authors plan to explain how climate change may affect cotton yields and provide recommendations on how the textile sector can mitigate these changes. The study also evaluates the role of sustainability metrics, such as the Higg Materials Sustainability Index (Higg MSI), to assess cotton's environmental impact. The government's initiatives to promote renewable energy sources also need to be evaluated based on the points of view of O. Durru and co-author [3] who have proven the economic efficiency of using renewable energy sources in the textile industry of Kazakhstan.

The specific objectives of the study include summarizing information on the impact of temperature and precipitation on cotton yields, as well as prospects for the development of the cotton industry taking into account climate change, and evaluating government programs that support and implement energy-saving technologies.

For the first time, this study connects the outcomes of the climate change scenario analysis is connected with government support and technological innovations in the textile industry of Kazakhstan. The research model thus developed holistically considers the climatic factors, technological advancement and the currently growing socio-

economic features thereby helping to formulate of plan of action towards adapting the industry in the best way possible. Contrary to other papers that focus on climatic or economic conditions, this study considers technological adjustment, sustain-able cotton varieties, and government supportt.

Building upon the works of Yusupov and Tastanbekov, which identified the impact of temperature and precipitation on the yields of the cotton, the study integrates the assessment of innovations and how they can be integrated. Thanks to the best practices implemented through practical tools such as Higg MSI and Higg PM sustainability indices, it was possible to transfer international approaches to the development of sustainable textile industry to Kazakhstan and ensure environmental and economic sustainability of the sector.

They utilize technologies like precision irrigation; solar-run water pumps; and sustainable cotton varieties to attain predict-able yields and reduce resource expenses. This approach based on scenario modelling of the IT infrastructure, definition of the appropriate IT solutions and government participation emphasizes the originality and relevance of the research for the Kazakhstani textile industry.

Methods

When analyzing the impact of climate change on the textile industry of Kazakhstan, the study uses the method of scenario analysis. Data on average temperatures, precipitation, and cotton yields over the past decade

were incorporated into predictive models for the next 20 years. Scenarios ranging from the most favorable in terms of temperature and humidity, as well as government support, to the opposite, with their intermediate values, were used for modeling.

Climate variables were statistically compared with cotton yield data using a regression model. Additionally, correlation analysis was employed to evaluate the relationship between renewable energy adoption and the economic efficiency of textile enterprises. Advanced modeling tools, including Python-based libraries, were utilized to ensure accurate and transparent results.

Results and Discussion

Studies of changes in climatic conditions and their impact on cotton production and the textile industry in Kazakhstan over the next two decades have revealed new trends. The analysis highlights an increase in extreme weather events, significantly affecting cotton yields, particularly in regions like Turkestan. As for the climate, the study used data on average annual temperatures and precipitation, average historical cotton yields over the previous five years and for the forecast period from 2025 to 2045. The hypothesis of the work is that relatively low cotton production, combined with an increase in temperature and a decrease in precipitation, can be countered by government intervention and the introduction of technology.

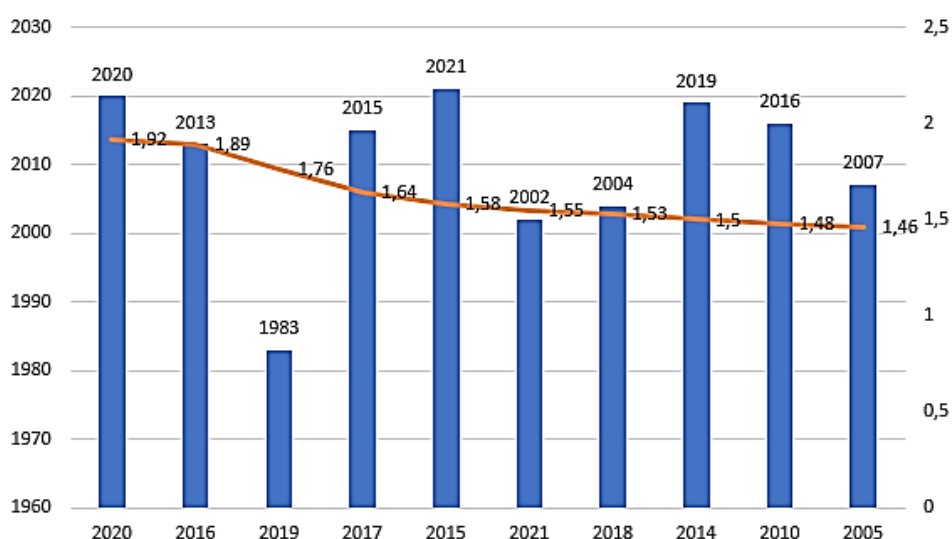


Fig. 1

Analyzing the data obtained for the regions of Kazakhstan over the past 10-20 years, it is possible to note trends in temperature increase and changes in precipitation. Fig. 1 also shows that the highest temperature anomalies were observed in 2020: the temperature deviation from the norm averaged 1.92°C. 2016 took second place with an indicator of 1.89°C. This indicates significant differences in climatic parameters, which can have a significant impact on agricultural activities.

According to available information, the Turkestan region, which is the main producer of cotton, is the most sensitive to the effects of climate change. Figure 2 shows an increase in the average temperature in this area between 2015 and 2023, which affects yields.

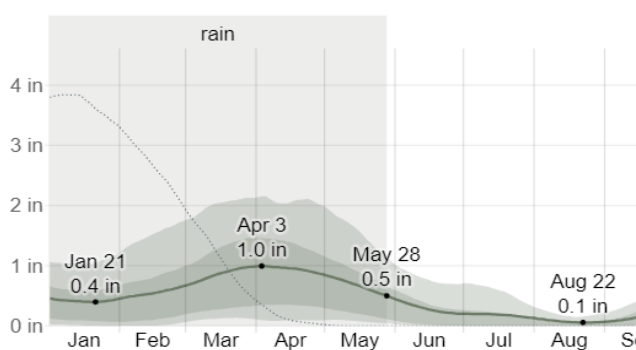


Fig. 3

The study recommends implementing sustainable technologies, such as drought-resistant cotton varieties and advanced irrigation systems, supported by government programs. These solutions aim to maintain yields under increasingly adverse climatic conditions.

The dynamics of the cotton harvest in Kazakhstan over the past five years is obvious based on the data presented in Figure 4. From 2019 to 2023, the cotton yield demonstrated significant variability, largely influenced by climatic factors. For instance, in 2023, the harvest amounted to 300 thousand tons, which, despite fluctuations, marked a significant recovery compared to the preceding years. The amplitudes of such fluctuations are associated with changes in temperature and precipitation, as shown by scenario analysis.

Taking into account the information given in Figure 3, the amount of precipitation in the Turkestan region also differs, and increased humidity was noted in March and April.

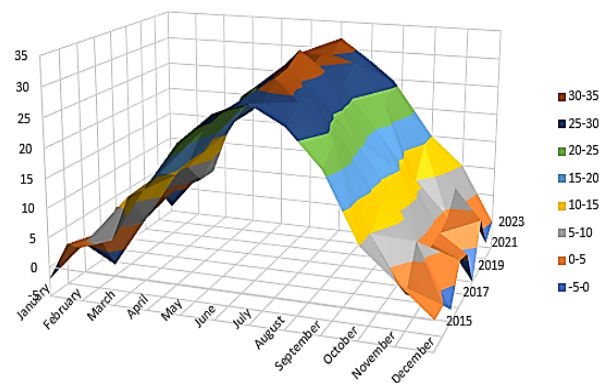


Fig. 2

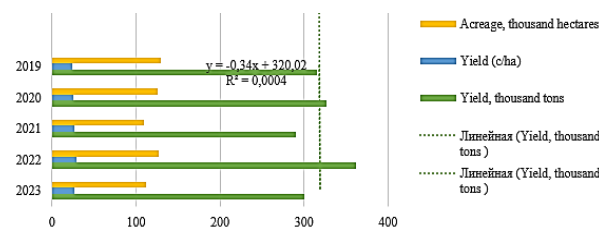


Fig. 4

In the context of the article, we take into account the Turkestan region, because the region is the only region in which there are cotton fields, as well as about 67% of all greenhouses, where more than 300 thousand tons of cotton are produced annually with the support of 22 cotton processing plants and 25,000 people employed in this field [7]. The region's reliance on such a concentrated and climate-sensitive crop makes it particularly vulnerable to ongoing environmental changes, necessitating immediate intervention.

Three scenarios have been developed to assess future changes: optimistic, pessimistic and moderate. It is assumed that all of them contain data on temperature, precipitation and government support. The modeling was accomplished using statistical tools like Python libraries - Pandas, NumPy, during which climate records and economic stats were used. Moreover, the Higg MSI metrics at the material level were used in the model due to the fact that the effects on the environment of the cotton itself were important to foresee, including carbon footprint and water consumption.

The main part of the model is the `predict_cottonfield_with_past` function, which returns the percentage of cotton harvest and requires entering a string with data on temperature, precipitation and the level of government support. Data for a particular day is obtained as input to the above function, and based on the 'type of scenario', optimistic, pessimistic or moderate, cotton yield is determined (Fig. 5).

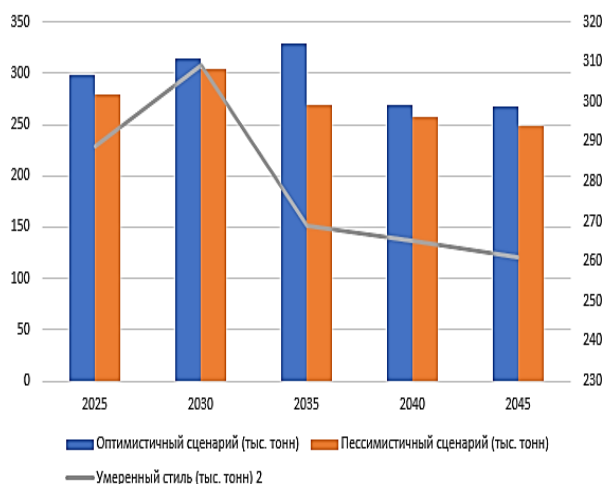


Fig. 5

An optimistic view suggests that where there is support from the government and where new technologies reduce the severity of the temperature regime and precipitation, the negative effects of temperature are offset. In this case, the tendency to increase cotton yields remains at a constant level until 2035, after which a decrease in yields is expected due to an increase in temperature to 1.5 °C and above.

The analysis of the worst-case scenario shows that cotton yields will fall rapidly in harsh climatic conditions, especially in the absence of government assistance and the use of technology. In this case, by 2035, the yield will be 269 thousand tons, which is characterized by high risks for the textile industry.

In the average scenario, the yield decreases gradually as the temperature rises and approaches optimal values. However, even in this case, an increase in temperatures beyond 1.5 degrees leads to noticeable losses in yield. The study emphasizes that without immediate intervention and adoption of sustainable practices,

the economic sustainability of the cotton and textile industries will be severely impacted.

Interpretation of the results

The simulation results confirm the hypothesis that climate change to a moderate level, namely up to 1.5°C, can be partially mitigated through the introduction of new technologies, as well as government support to stabilize yields until 2035. This stabilization can be achieved by transitioning from a narrow focus on climatic variables to a comprehensive ecological and innovative management system that accounts for environmental sustainability, technological advancements, and socio-economic factors.

The analysis underscores the importance of advanced measures such as drought-resistant cotton varieties, precision irrigation systems, and the use of renewable energy sources in cotton processing. Innovative farming technologies, including AI-driven predictive models and IoT-based sensors for real-time monitoring of weather, soil, and crop health, are essential for optimizing production processes. Moreover, leveraging genetic engineering to develop climate-resilient cotton varieties could significantly enhance adaptability to extreme weather conditions.

To address the broader environmental impacts of cotton production, sustainability frameworks like the Higg MSI and Higg PM were integrated into the analysis. These tools revealed the critical role of reducing water consumption and carbon emissions, which are key contributors to the overall environmental footprint of the textile industry. For instance, switching to organic farming practices and implementing water recycling systems in cotton processing plants could reduce resource use by up to 40%.

An increase in temperature to 2°C and above drastically reduces cotton yields, even with government support. Stabilization becomes achievable only if adaptive practices are actively introduced. Crop diversification strategies, such as integrating alternative drought-tolerant crops, could also help stabilize agricultural output. Expanding sustainable practices, such as regenerative agriculture and closed-loop systems, can further mitigate negative impacts.

Limitations of the study

The disadvantages of the study are related to the unpredictability of climate forecasts for several decades and the availability of technologies not provided for by the model. While methods like High MSI were used when assessing potential environmental effects, more development is required for these frameworks to be tailored to Kazakhstan's conditions, including water deficiency and soil erosion.

However, the factors that appear to have been excluded in the current research are social and economic factors. For instance, the type and extent to which farmers are willing and able to embrace new technologies depends on socio-economic factors which have not been discussed in the current research. Other areas that future research should focus on include failure to consider broadly prevailing market issues including demand for more environmentally friendly textiles or fluctuations in prices of raw materials like cotton.

It also assumes that support from the government will still be carried on, something may not valid politically and economically. In addition, the model does not take into account the impact of changes in global market conditions and any other shocks that may occur to the textile industry market [8].

Practical application

The results of this study will be useful for the development of adaptation measures for the textile industry in Kazakhstan [9]. Adequate subsidiary support from the Government will help to solve the problem of fluctuations in total cotton production through the introduction of sustainable technologies and water management systems. The government should also invest more in production of renewable energy technologies such as solar and wind energy to minimize the sector's dependency on fossil energy. Perhaps, it is high time to establish specialized research centers for sustainable cotton production and processing that will foster the search for proper innovation.

Therefore, the national performance report on sustainability indicators is another significant recommendation. If Higg MSI and Higg PM and similar tools feed into this platform, individuals and factories could be held to ac-

count, producers could be verified as meeting international standards and gaining access to new markets.

Global cooperation should also become a fundamental element of adaptation practices. Possible cooperation with countries experienced in sustainable cotton growing, such as India, Egypt, and Turkey, may help transfer technology and improve knowledge. Furthermore, it could be highly appropriate for Kazakhstan to embrace international programs such as the Better Cotton Initiative (BCI) to enhance the country's best practice benchmark in the production of sustainable cotton.

Suggestions for future research

Concerning the scientific prospects of future research, several pivotal directions should be underlined. Creating a new generation of eco-friendly varieties with high drought tolerance is paramount for development. These varieties should be designed to perform under high temperatures and low water supply, ensuring steady production regardless of weather conditions. Further, the study should focus on the potential inherent in cotton to increase its capacity for carbon storage, helping to combat climate change.

Subsequent research should assess the socio-economic effects of implementing sustainable practices, especially for smallholder farmers. It is important to understand how shifts in agricultural practices alter people's lives and labor market opportunities, considering rural development that promotes equity. Another area of interest should be the ability to achieve better traceability within the cotton supply chain and reward sustainable practices using blockchain technology.

If Higg MSI and similar sustainability integrity metrics were refined to include on-site soil properties (OSSP) metrics like SOC, pH, and water stress conditions at the production location of apparel firms, this could add to a more granular understanding of site impacts. Further, studies on the feasibility of generating power from renewable sources in textile processing plants may highlight possible ways to cut costs and reduce emissions. For example, using solar energy to power cotton gins or using biomass by-products for energy purposes within the industry could drastically

decrease the total carbon emissions associated with the industry.

This implies that an interdisciplinary approach combining climate science, economics, and technology is crucial in facilitating the formulation and implementation of effective climate change solutions. Maintaining partnerships with international institutions such as FAO and UNDP might create opportunities for financing and consultancy that would enhance the shift to sustainable practices in the textile sector in Kazakhstan.

CONCLUSION

Therefore, it is suggested to build and improve several areas for the implementation of an optimistic scenario and to prevent the emergence of a pessimistic scenario in the textile industry of Kazakhstan. The first recommendation is the adoption of new sustainable technologies, including the development of drought- and heat-resistant cotton varieties. These varieties are essential for stable yields under conditions of climate change. Similar varieties of cotton have already been developed and have shown promising results in other regions of the world by reducing the effects of heat and water stress through research and pilot projects in other cotton-growing countries, such as India and Egypt [10]. These varieties could enhance resilience in Kazakhstan, particularly in the Turkestan region, where crops are highly exposed to climate risks, especially in cotton production.

Beyond crop varieties, technologies that optimize water use, such as precision irrigation and closed water recycling systems, require urgent attention. For example, drip irrigation has been shown to reduce water usage by 40%-60% while maintaining or even increasing crop yields. This paper argues that the implementation of such systems in Kazakhstan's cotton fields could help solve the issue of water deficiency in the region and align with international sustainability goals. From a technological perspective, these systems not only conserve resources but also reduce production overheads in the long term, making them economically viable for both farmers and industrialists.

The social factor can be divided into two aspects: government support and farmer education. Government subsidies are crucial for pioneering new technologies, alongside incentives to encourage the development and adoption of innovative solutions. This includes direct investment in research programs focused on breeding climate-resilient cotton varieties and building strong partnerships with international organizations that have extensive expertise in agricultural research. Additionally, farmer training programs are essential to ensure that new technologies are used appropriately and effectively. Without such training, the potential benefits of these innovations may remain unrealized. Without an understanding and educational campaign, the best technologies are likely to achieve an impact much below what was intended.

As for climate change adaptation, to be able to cope with the expected changes, managers should have a rather flexible organization of the product unloading and ensure that risk management programmes include the incorporation of weather forecasting systems. However, the above recommendation should be approached with caution. For instance, incorporating a weather monitoring system may improve risk appraisal and protection, but it will require large investments in technology and human resources. To avoid putting a large number of farmers in compromising and risky situations, the effectiveness of such measures should be evaluated with reference to their cost-benefit analysis through pilot projects.

The idea of utilizing renewable energy sources, for instance solar energy for irrigation, is yet another suitable solution. For example, the replacement of diesel water pumps with solar-powered water pumps has proven effective in decreasing energy budgets and GHG emissions in irrigation activities. Nevertheless, the initial costs of renewable energy systems remain unaffordable for most farmers. This gap could be addressed through government grants or public-private partnerships, enabling wider adoption of these technologies.

In order not to end up with a pessimistic prognosis, it is crucial to act in the worst-case scenario and prepare for environmental

shrinkages. Failure to invest in affordable and more sustainable technologies, as well as weak handling of climate change risks, could severely reduce yields and compromise the textile business. It argues that strong ecological management frameworks are central to managing these risks. Measures inclusive of the Higg Materials Sustainability Index (Higg MSI) and the Higg Product Module (Higg PM) offer comprehensive tools for assessing and enhancing the ecological efficiency of textile manufacturing. Their integration into Kazakhstan's industry could assist in identifying weak links and encouraging best practices that will enable sustainable development throughout the chain.

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