SUSTAINABLE GREENHOUSE-GROWN COTTON RESEARCH REPORT

In association with Wageningen University Research and Dutch Cotton

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SUSTAINABLE GREENHOUSE COTTON CULTIVATION IN THE NETHERLANDS: ADVANCING ENVIRONMENTAL STEWARDSHIP IN COTTON PRODUCTION

The Sustainable Greenhouse Cotton Cultivation research project represents a pioneering initiative to explore the feasibility and potential of growing cotton in a controlled greenhouse environment in the Netherlands. With a primary focus on sustainability, the project aimed to investigate the environmental and economic implications of greenhouse cotton cultivation and its role in advancing sustainable agriculture and textile production. Through collaboration between G-Star, and agricultural experts from Dutch Cotton and Wageningen University and Research (BU Greenhouse Horticulture) the feasibility and potential of greenhouse cotton cultivation as a sustainable alternative to traditional open-field methods was investigated.

OBJECTIVES

1. Investigate the quality, yield, and fiber properties of greenhouse-grown cotton varieties under different environmental conditions and cultivation techniques.
2. Assess the environmental footprint of greenhouse cotton cultivation, including water usage, energy consumption, greenhouse gas emissions, and chemical inputs, compared to conventional cotton farming methods.
3. Evaluate the potential for reducing environmental impact and resource utilization through optimized greenhouse management practices, such as precision irrigation, integrated pest management, and renewable energy adoption.
4. Analyze the economic viability and market potential of greenhouse cotton cultivation, considering production costs and value chain integration.

KEY ACTIVITIES

1. Greenhouse setup and infrastructure: Design and establish greenhouse facilities optimized for cotton cultivation, incorporating climate control systems, irrigation infrastructure, renewable energy sources, and resource-efficient technologies.
2. Crop cultivation and management: Implement cultivation protocols tailored to greenhouse cotton production, focusing on sustainable agronomic practices, soil health management, and biodiversity conservation.
3. Environmental impact assessment: Conduct comprehensive life cycle assessments and environmental impact analyses to quantify the environmental benefits and trade-offs of greenhouse cotton cultivation compared to conventional methods.
4. Economic feasibility analysis: Assess the financial viability and return on investment of greenhouse cotton cultivation through cost-benefit analysis.
5. Stakeholder engagement and knowledge dissemination: Engage with stakeholders from the agricultural, textile, and sustainability sectors to share research findings, promote dialogue, and facilitate knowledge exchange on sustainable cotton production practices.

OUTCOMES

1. Identification of best practices and strategies for reducing environmental impact, improving resource efficiency, and enhancing socio-economic resilience in cotton farming and textile manufacturing.
2. Generation of scientific evidence and data-driven insights to inform industry stakeholders, and researchers about the potential of greenhouse cotton cultivation as a sustainable alternative to conventional methods.
3. Promotion of innovation, collaboration, and capacity-building initiatives to accelerate the adoption of sustainable cotton production practices and technologies.
4. Contribution to the advancement of sustainable development goals, climate resilience, and environmental stewardship in the agricultural sector, both regionally and globally.

The Sustainable Greenhouse Cotton Cultivation research project represents a significant step towards making the cotton industry more resilient by promoting sustainability, and fostering resistance in agricultural systems. Through collaboration and engagement, the project strove to catalyze positive change and create a more sustainable future for cotton production and textile manufacturing in the Netherlands and beyond.

BENEFITS OF GROWING COTTON IN A GREENHOUSE

Growing cotton in a greenhouse offers numerous benefits, including:

1. **Maximized Yields:** Greenhouses allow growers to regulate factors like temperature, humidity, light levels, and ventilation, creating ideal conditions for plant growth significantly improving yields.

    The outcome of the study showed a substantial reduction in land use, with a significant increase in efficiency per hectare. The best plants in the study yielded 1.2kg per m2, which is 5 to 23 times more cotton compared to average outdoor plants. New cultivation systems will be tested to further optimize yield.

2. **Extended Growing Season:** Greenhouses provide a controlled environment, allowing cotton to grow beyond their natural season. This enables growers to produce crops year-round, increasing overall productivity.

    For the purpose of this research, it was noted that cotton could be harvested until the end of November without significant additional heat and lighting.

3. **Protection From Weather:** Greenhouses shield plants from harsh weather conditions such as frost, hail, excessive heat, wind, and heavy rain, minimizing damage and ensuring consistent growth.

    By growing in a greenhouse, cleaner cotton was produced as no sand or dust polluted the cotton. Additionally, the whiteness level outperformed outdoor plants.

4. **Pest And Disease Control:** By enclosing plants, greenhouses help prevent infestations from pests and diseases, reducing the need for pesticides and minimizing crop loss.

    In this study the plants were grown naturally without the use of synthetic/chemical pesticides.

5. **Water Conservation:** Greenhouse environments incorporate efficient irrigation systems and water management practices, reducing water usage compared to open-field cultivation.

   For this study it was estimated that up to approximately 95% of water was saved per kilo of cotton. All water used was collected rainwater, which was recycled again.

6. **Reduced Soil Erosion:** Growing crops in pots within a greenhouse environment minimizes soil erosion compared to traditional field cultivation. Pots help contain the substrate, preventing it from being displaced by wind or water erosion. This reduces soil loss, preserves soil fertility, and maintains soil health over time.

   Different substrates were used in this study, and due to planting in pots, there was no impact on soil.

7. **Local Production:** Greenhouses allow for local production, reducing the need for long-distance transportation and promoting security and sustainability within communities.

   The cotton in this project travelled 643km from the greenhouse to final product. The average transportation route for a final apparel product (excluding the transportation of raw material) is approximately 9.696km.

8. **Plant Longevity:** A greenhouse environment makes it possible to keep plants for several seasons.

   The best plants from the research were selected to produce seeds and were also used for creating cuttings. Further research is needed to determine the necessity of this practice, although it is worth noting that the oldest plants at Bleiswijk are currently 4 years old.

Overall, growing in a greenhouse offers a controlled and protected environment that enhances crop productivity, quality, and sustainability while reducing risks associated with outdoor cultivation.

GREENHOUSE PROTOCOL

Location	Bleiswijk, The Netherlands
Size of greenhouse	144m^2
Variety	Buranda
Number of plants	100 plants
Growth timeline	March-December

GROWTH SCHEDULE

Gutters:

Single and double rows were utilized in the greenhouse, offering the flexibility of having 5 double rows and 2 single rows on each side. In this trial, half of the plants were grown in single gutter rows, while the other half were grown in double gutter rows. It was observed that single gutter rows performed better, as they provided more space for the development of side shoots.

Substrate:

Two different substrates were used in the trial; peat and rockwool.

Composition peat substrate

- 15% peat litter fraction 1
- 70% peat litter fraction 0
- 15% perlite fraction 3 (0-6 mm)
- 3.1 kg Dolokal
- 0.5 kg PG mix NPK 14-16-18

Grow cubes

- Small rockwool cubes of 1 cm^3

Light:

Natural light exclusively illuminated the area, with the plants receiving sunlight without the aid of artificial lighting. Sun screens were employed during the hours of 11 am to 3 pm when outdoor light levels exceeded 800 watts/m^2.

Heating:

Heating was kept at 16°C at night and 18°C in the day to optimize conditions but also to prohibit high humidity during flowering to reduce risk of botrytis.

Ventilation:

Ventilation was provided by opening windows when temperatures exceeded 25°C.

Humidity:

The objective was to regulate humidity levels between 60% and 90% by employing fogging and heating techniques.

Fertilization:

Fertilization involved adding a specific mix of fertilizers to the water supplied to the plants.

Watering:

Several times per day based on the size of the plants, the amount of light and weight of plants.

Variety:

The Buranda variety served as the primary testing cultivar in the trial due to its compact growth and robust cotton bulb production.

Treatments:

In this trial 2 substrates will be compared with 2 plant densities.

MEASUREMENTS

In our trial cultivation of cotton within a greenhouse environment, a comprehensive set of measurements was conducted to evaluate various aspects of the growing process. These measurements included:

Production:

- Assessment of production levels for each treatment applied during the trial. For example, production output from growing in rockwool, peat etc.
- Calculation of production per square meter of greenhouse space, providing insights into efficiency and yield potential.

Quality of the Cotton:

- Evaluation of cotton fiber quality, including characteristics such as length, strength and fineness, to determine the suitability of the harvested product for market.

Light Level:

- Monitoring of light intensity within the greenhouse to ensure adequate levels for optimal plant growth and development.

Climate:

- Measurement of environmental parameters such as temperature, humidity, and CO2 levels to maintain favorable growing conditions for the cotton plants.

Amount of Water and Fertilization:

- Recording of water usage and fertilization practices to assess resource efficiency and sustainability of cultivation methods.

Biological Control and Chemical Crop Protection:

- Observation of biological control measures implemented to manage pests and diseases, along with monitoring of chemical crop protection usage to evaluate effectiveness and minimize environmental impact.

By meticulously tracking these key measurements, we were able to gain valuable insights into the performance of cotton cultivation in a greenhouse setting. This data has informed our understanding of optimal cultivation practices and will guide future efforts to enhance productivity and sustainability in greenhouse cotton production.

RESULTS OF GROWING COTTON IN A GREENHOUSE

Cultivation in 2023 commenced in early March with the preparation of plant material for the trial. Plant propagation involved both seeds and cuttings. Seeds harvested in 2022 were extracted from the cotton balls for planting. Additionally, existing plants from 2022 were retained, and new shoots were cultivated for use as cuttings.

Cuttings were made on March 10, 2023, using both peat and rockwool cubes. However, the cuttings in peat did not exhibit satisfactory growth by March 17, whereas those in rockwool showed better progress. Concurrently, seeds were planted on March 10, 2023, with the first signs of germination observed on March 14, 2023. Subsequently, the seedlings were transplanted into larger greenhouse compartments on March 17, 2023.

Plants from the previous year began flowering in mid-April 2023 and the first cuttings flowered on May 3, 2023, followed by the first seedlings on May 31, 2023. Harvesting commenced in early August and continued until November. Despite ongoing growth and cotton production during this period, the quality of the cotton did not meet the desired standards.

PRODUCTION

The outcome of the study presented valuable insights into the productivity and yield potential of greenhouse-grown cotton plants. By analyzing the production per plant, we were able to assess the effectiveness of various cultivation methods and environmental factors in optimizing cotton yield.

The findings presented in this chapter contribute to our understanding of sustainable cotton production practices and highlight the potential of greenhouse cultivation as a means to improve yield and productivity while reducing environmental impact. The table below presents the results from the best performing row:

Single row	
Substrate	Peat
Plant	Seed
Average weight cotton ball	5.1
Number of plants	12
Fresh weight cotton Per plant (g)	602
Plants per m2	1.2
Fresh weight cotton per m2	903
Mould (%)	29
Missed by mould (g)	262
Possible yield per m2	1165

The table below, based on “LCA update of cotton fiber and fabric life cycle inventory” by Jewell provides data on cotton yield per square meter (m^2) in four major cotton-producing countries: India, China, USA, and Australia. Cotton yield is a crucial metric in assessing agricultural productivity and plays a significant role in the global cotton market. Understanding the variations in yield across different regions offers valuable insights into the efficiency and effectiveness of cotton cultivation practices in each country.

	Yield **kg/m²**	**% Difference** **kg/m²**	**Times different** **kg/m²**
The Netherlands	1.2		
India	0.05	2300%	23x more cotton
China	0.14	757%	8x more cotton
USA	0.09	1233%	12x more cotton
Australia	0.2	500%	5x more cotton

During the cultivation of cotton in 2023, several remarkable observations were made:

- The most effective treatment resulted in a yield of 1.2 kg of cotton per square meter. The top-performing plants in the study yielded 5 to 23 times more cotton compared to average outdoor plants.
- Early Flowering: Cotton plants propagated from cuttings exhibited flowering approximately two weeks earlier than those from seeds.
- Increased Plant Height: Cotton plants in 2023 displayed increased height, reaching up to three meters before being pinched and in total up to 4 meters compared to outdoor plants, which typically reach 1.2 meters.
- Humidity Issues: High relative humidity (RV) levels at crucial times led to the development of diseases such as Botrytis and Mucor in some cotton balls.
- Production Comparison: Production from seeds was found to be comparable to production from cuttings, as observed when comparing production levels in grow cubes.

These observations provide valuable insights into the cultivation of cotton in a greenhouse environment and highlight areas for optimization and improvement in future cultivation practices.

CLIMATE CONDITIONS

The success of greenhouse cotton cultivation heavily relies on creating and maintaining optimal climate conditions within the greenhouse environment. Here we delve into the crucial factors of light and temperature, exploring their impact on cotton growth and productivity.

Light

Light is one of the most critical environmental factors affecting plant growth and development. In greenhouse cotton cultivation, the availability and quality of light play a pivotal role in determining plant health, flowering, and ultimately, yield. In this study only natural light was used to provide the energy that was necessary for photosynthesis and overall plant growth. In this study screens were used to regulate light intensity and distribution, to prevent excessive sunlight exposure, and to reduce the risk of heat stress.

Temperature

Temperature is another crucial climate factor that significantly influences the growth and development of greenhouse cotton. Maintaining optimal temperature levels within the greenhouse is essential for ensuring plant health, promoting flowering and fruiting, and achieving high yields.

During the daytime, maintaining an optimal temperature range is crucial for promoting photosynthesis, growth, and flowering in cotton plants. Excessive heat can lead to heat stress, reduced photosynthetic efficiency, and decreased yield, while temperatures that are too low can slow down growth and development.

Nighttime temperatures also play a critical role in cotton cultivation, influencing processes such as respiration, nutrient uptake, and flowering. Maintaining stable nighttime temperatures within the greenhouse helps prevent stress and ensures consistent plant growth and development.

In this study the greenhouse was kept at a temperature of 16°C at night and 18°C during the day. To enhance energy efficiency, this project employed insulated glazing, automated climate control systems, and screens to regulate temperature. Additionally, in instances where supplementary heating was required, gas was utilized as the heating source. For the full trial 13 m^3/m^2 of gas was used.

By understanding and carefully managing these crucial climate factors, growers can create optimal growing conditions for cotton plants, maximizing yield, quality, and overall productivity.

WATER AND FERTILIZATION

Water management and fertilization are critical aspects of greenhouse cotton cultivation, significantly impacting plant growth, yield, and fiber quality. In this chapter, we explore the strategies and techniques used to optimize water usage and fertilization practices in greenhouse-grown cotton.

Water Usage

Water is essential for cotton plant growth and development, playing a crucial role in various physiological processes such as photosynthesis, nutrient uptake, and transpiration. In greenhouse cotton cultivation, efficient water management is essential to ensure optimal plant health and productivity while minimizing water wastage and environmental impact. In this study, only rainwater was used for irrigation, with 35% of water being recycled again for reuse.

Irrigation Systems

Greenhouse cotton cultivation often relies on advanced irrigation systems to deliver water efficiently to the plants. The system used in this study included drip irrigation allowing the growers to precisely control water application and minimize water loss.

Water Recycling

To enhance sustainability and reduce environmental impact, the growers used water recycling systems. These systems collected and treated runoff water, allowing it to be reused for irrigation, thereby conserving water resources and reducing overall water consumption.

Research conducted by Dagdelen et al. (2006) demonstrated a direct correlation between cotton production and irrigation levels in Turkey. They found that a water usage of approximately 900 mm resulted in a cotton yield of around 5000 kg/ha. However, these figures are influenced by various factors such as soil type, climate, fertilization, and cotton variety. Research by Mekonnen, M. M., & Hoekstra, A. Y. (2012) estimates that it takes approximately 10,000 liters of water to produce 1 kilogram of cotton.

In an effort to minimize water usage without compromising the health and vitality of our crops, we closely monitored our irrigation practices. Below is a summary of the monthly water usage on our cotton farm, resulting in an average of 800 liters of water per square meter throughout the full growing season.

Moreover approximately 35% of the water utilized was recycled, resulting in an additional conservation of 280 liters and achieving a total saving of approximately up to 95%.

Month	Water (CC) per plant with day ranges in that month
April	250–1500
May	500-1600
June	1000-6000
July	1000-5000
August	600-5000
September	800-2500
October	200-1000
November	200-500

In greenhouse cultivation, efficient water management is crucial. By implementing systems that allow for the reuse of water, greenhouse growers can significantly reduce water consumption compared to outdoor cultivation. The only losses incurred are within the system itself, including plant uptake and evaporation for cooling purposes.

Fertilization

Fertilization is essential for providing cotton plants with the necessary nutrients for healthy growth, development, and high-quality fiber production. In greenhouse cotton cultivation, precise fertilization practices are crucial to ensure optimal nutrient levels while minimizing environmental impact and nutrient runoff.

Fertilizer Application

In this study, growers carefully monitored soil nutrient levels and applied fertilizers as needed to meet the specific nutritional requirements of the plants. A fertilizer mixture was provided with each watering. Regular measurements of drain water and fertilizer levels in the substrate were taken to ensure that fertilization did not limit plant growth.

By implementing efficient water management and precise fertilization techniques, growers were able to optimize plant health, yield, and fiber quality while minimizing environmental impact and resource usage.

PEST CONTROL

Traditionally, cotton cultivation has been heavily reliant on chemical pesticides to combat pests and diseases. In this study we tried to eliminate the use of these harmful chemicals while maintaining healthy and high-yielding cotton crops.

The study utilized advanced greenhouse technology to create a controlled environment suitable for cotton cultivation. By carefully regulating factors such as temperature, humidity, and light levels, researchers were able to create optimal growing conditions for cotton plants. Additionally, natural pest control methods such as biological pest management and companion planting were employed to keep pests at bay without the need for chemical intervention.

One of the key highlights of the study was the successful prevention of pest infestations and diseases without the use of chemical pesticides. By closely monitoring the greenhouse environment and implementing organic pest control methods, researchers were able to achieve healthy and pest-resistant cotton crops throughout the cultivation period. The figure below shows the natural predators used to eliminate the existence of different potential diseases.

Predator	**Disease**
Aphids	Aphidoletes aphidimyza, Chrysoperla carnea, Digyphus isaea
Spider mite	Neoseiulus californicus, Phytoselius, Phytoseilus persimilis
Thrips	Orius laevigatus, Amblyseius swirski
White fly	Enermix, Eretmocerus eremicus

The results of the study could have significant implications for sustainable cotton production. By eliminating the use of chemical pesticides, greenhouse-grown cotton could not only reduce environmental pollution but could also minimize health risks for farm workers and surrounding communities.

Moreover, the method showcased in this study offers a viable alternative for cotton cultivation in regions where chemical pesticide use is restricted or environmentally sensitive. By harnessing the power of greenhouse technology and organic pest control methods, researchers have demonstrated a viable pathway for chemical pesticide-free cotton cultivation, paving the way for a more sustainable future for the cotton industry.

COMPARISON BETWEEN GREENHOUSE-GROWN AND OUTDOOR-GROWN COTTON

Both greenhouse and outdoor environments offer unique advantages and challenges. This chapter compares the cultivation of cotton in a greenhouse environment to traditional outdoor cultivation, focusing on factors such as water usage, yield and environmental impact.

Water Usage

- Greenhouse Cotton: In the greenhouse environment, cotton cultivation requires approximately 800 liters of water per square meter or 400 liters of water per plant over the growing season.
- Outdoor Cotton: Outdoor-grown cotton typically relies on natural rainfall for water supply, supplemented by irrigation as needed. The water usage for outdoor-grown cotton can vary depending on local climatic conditions and irrigation practices. It is estimated that it takes approximately up to 10,000 liters of water to produce 1 kilogram of cotton.
- Greenhouse Cotton: The yield of greenhouse-grown cotton ranges from 0.5 to 1.2 kg per m^2, or approximately 450 to 600 grams per plant, depending on factors such as cultivation techniques and environmental conditions.
- Outdoor Cotton: Outdoor-grown cotton yields can vary widely depending on factors such as soil quality, climate, and pest pressure. Yields typically range from 0.05 to 0.2 kg per m^2, or approximately 100 to 300 grams per plant.

Pesticide Use

- Greenhouse Cotton: Greenhouse cultivation of cotton allows for more precise pest management strategies, reducing the need for chemical pesticides. Integrated pest management (IPM) techniques, including the use of biological controls and monitoring systems, are commonly employed in greenhouse environments.
- Outdoor Cotton: Outdoor cultivation of cotton generally requires more frequent pesticide applications to control pests and diseases. Factors such as pest pressure, weather conditions, and crop rotation practices can influence the amount of pesticides used in outdoor cotton cultivation.

Environmental Impact

- Greenhouse Cotton: Greenhouse cotton cultivation allows for precise control over environmental conditions, leading to higher yields and reduced water usage compared to outdoor cultivation. However, greenhouse cultivation requires additional energy for heating, which contributes to its environmental footprint.
- Outdoor Cotton: Outdoor cotton cultivation relies on natural environmental conditions, reducing the need for artificial inputs such as heating and lighting. However, outdoor cultivation may be more susceptible to pest infestations, diseases, and adverse weather conditions, which can impact yield and quality.

Growing cotton in a greenhouse offers unique advantages. Greenhouse cultivation provides a meticulously controlled environment, allowing for precise management of growing conditions. This results in consistently higher yields per square meter, reduced water usage, and superior quality control. While greenhouse cultivation may require additional energy input, the benefits of increased yield and resource efficiency often far outweigh the associated environmental footprint.

Ultimately, the choice of growing in a greenhouse depends on factors such as local climate, water availability, and sustainability goals. By understanding these differences, growers can make informed decisions to optimize their cotton production practices and achieve sustainable, high-quality yields.

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