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INTELLIGENT GREENHOUSE AUTOMATION AS A TRANSITION TO SUSTAINABLE AGRICULTURE

Jamanbayev Muratkali, Zholdasbai Tomiris, Iskakova Tolkynai, Masaeva Aigerim

Almaty Technological University, Almaty, Kazakhstan

Modern agriculture faces global challenges associated with climate change, population growth, and the depletion of natural resources. According to FAO forecasts, by 2050 world food production must increase by at least 60%, which requires the adoption of innovative technologies that ensure high productivity while reducing the negative impact on the environment.

Greenhouse crop production is an important tool for achieving stable yields; however, traditional methods face a number of limitations, such as high water and energy consumption, excessive use of fertilizers, and dependence on the human factor. In this context, the transition to intelligent automation becomes necessary, with digital technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and big data analytics playing a central role.

Intelligent automated control systems make it possible to continuously monitor key microclimate parameters (temperature, air and soil humidity, CO_2 concentration, light intensity), adaptively regulate irrigation and fertilization regimes, and predict plant development based on machine learning algorithms. This opens opportunities for significant optimization of resource consumption and for strengthening the resilience of agroecosystems.

Despite the growing interest in intelligent agriculture [1–3], questions remain regarding the practical assessment of such systems’ impact on production efficiency and their scalability in both industrial greenhouse complexes and small farming enterprises.

The aim of this study was to conduct a comprehensive assessment of the impact of intelligent greenhouse automation systems on production efficiency and environmental sustainability of crop cultivation.

For the experiment, an automated greenhouse module was developed in accordance with IoT architecture principles. The module was equipped with:

– IoT sensors for monitoring air temperature, soil and air humidity, light intensity, and CO_2 concentration;

– AI-based algorithms for adaptive control of the microclimate and irrigation;

– a data collection and processing platform for analyzing resource consumption and yield dynamics.

During a 90-day cultivation cycle of lettuce and tomatoes, the following parameters were recorded: energy consumption, water use efficiency, fertilizer input, and crop yield per unit area. Additionally, the stability of the microclimate was evaluated under different control regimes: traditional (manual) versus intelligent.

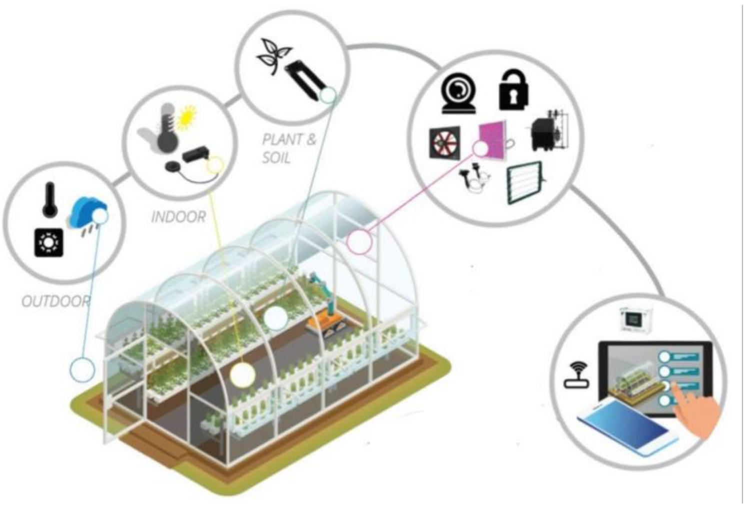

Figure 1 – Experimental greenhouse module equipped with IoT sensors

Comparative analysis demonstrated that the implementation of intelligent automation led to a significant reduction in resource consumption: water use decreased by up to 40%, energy consumption by 25%, and fertilizer usage by 30%.

At the same time, yield increased by 15–20% compared to traditional methods. Moreover, the intelligent system ensured greater stability of microclimate regulation, as confirmed by the reduced fluctuations in temperature and humidity parameters (Figures 2–4).

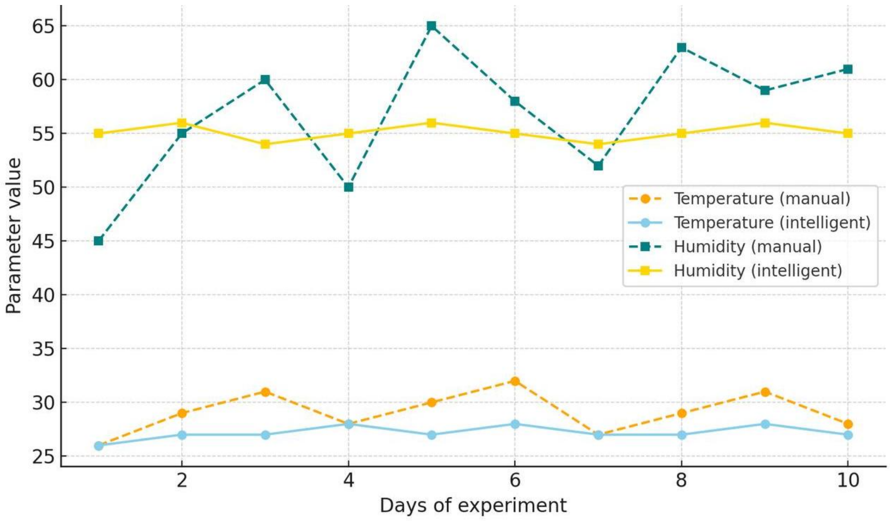

Figure 2 –Dynamics of Microclimate Stabilization

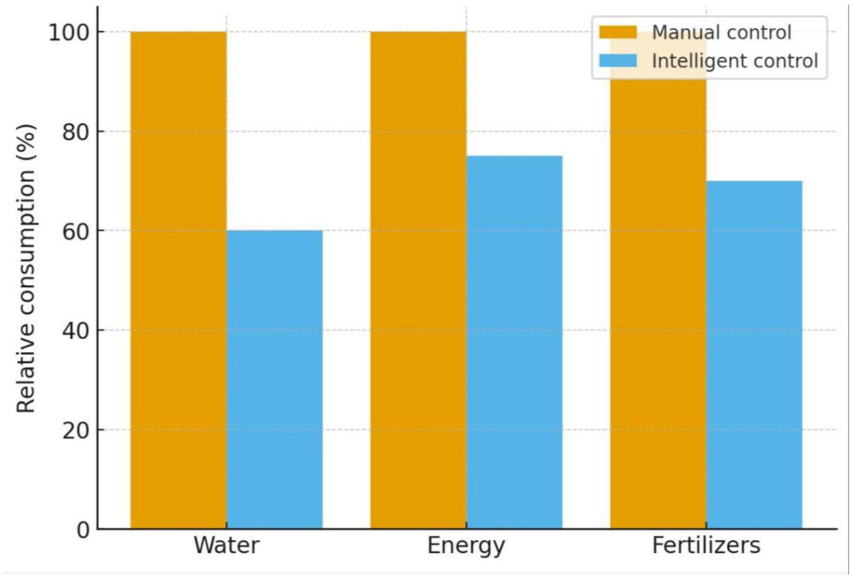

Figure 3 – Comprative resource consumption

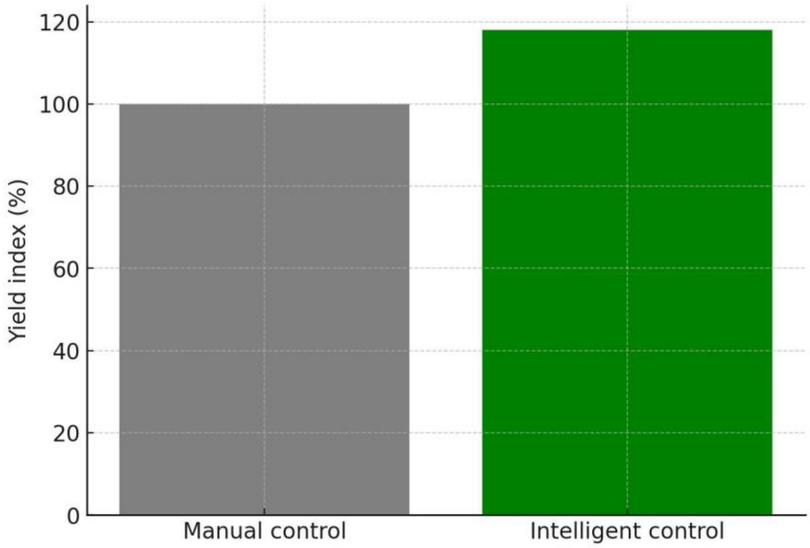

Figure 4 – Crop yield comparison

Conclusions

1. The use of intelligent greenhouse automation systems not only optimizes cultivation processes but also contributes to the implementation of sustainable agriculture principles.

2. The experiment confirmed that adaptive microclimate control creates optimal conditions for plant growth while minimizing environmental costs.

3. The integration of IoT and AI technologies reduces dependence on human intervention, ensuring more precise and timely decision-making.

4. The results indicate strong potential for the large-scale adoption of intelligent automation in both industrial greenhouse complexes and small farming enterprises.

5. The scaling of such solutions paves the way for the development of "smart agri-industrial ecosystems," which in the long term can contribute to global food security and sustainable agricultural development.

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