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MODERN PRINCIPLES OF DESIGNING DRIP IRRIGATION SYSTEMS IN GREENHOUSES

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Abstract. This article examines modern principles of drip irrigation systems in greenhouses based on information technology and automation. It analyzes the general principles of drip irrigation in greenhouses, including their control, measurement, and management, and explores an effective solution to the problem of regulating indoor microclimatic conditions. It also examines the implementation of automated processes for monitoring, measuring, and controlling environmental parameters using a multisensor system, its design using innovative methods and tools, and its application in real-world settings. The main objective of the system is to ensure normal conditions in the plant root zone, delivering water and fertilizers at optimal doses and low flow rates. Optimal control of the hydraulic system at low pressure is proposed.

Keywords: Greenhouse, hydraulic system, drip irrigation, smart metering, adaptive control, multisensor systems.

Аннотация. В данной статье рассматриваются современные принципы работы систем капельного орошения в теплицах на основе информационных технологий и автоматизации. Анализируются общие принципы капельного орошения в теплицах, включая их управление, измерение и регулирование, а также исследуется эффективное решение проблемы регулирования микроклимата внутри помещений. Рассматривается также внедрение автоматизированных процессов мониторинга, измерения и контроля параметров окружающей среды с использованием мультисенсорной системы, её проектирование с применением инновационных методов и инструментов, а также её применение в реальных условиях. Основная цель системы – обеспечение нормальных условий в корневой зоне растений, подача воды и удобрений в

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оптимальных дозах и с низким расходом. Предлагается оптимальное управление гидравлической системой при низком давлении.

Ключевые слова: Теплица, гидравлическая система, капельное орошение, интеллектуальный учет, адаптивное управление, многосенсорные системы.

Annotatsiya. Ushbu maqolada axborot texnologiyalari va avtomatlashtirish asosida issiqxonalarda tomchilatib sug‘orish tizimlarining zamonaviy tamoyillari ko‘rib chiqilgan. Issiqxonalarda tomchilatib sug‘orishning umumiy tamoyillari, jumladan, ularni nazorat qilish, o‘lchash va boshqarish masalalari tahlil qilinadi hamda yopiq mikroiqlim sharoitlarini tartibga solish muammosini samarali hal etish yo‘llari o‘rganiladi. Shuningdek, u ko‘p sensorli tizim yordamida atrof-muhit parametrlarini kuzatish, o‘lchash va nazorat qilish bo‘yicha avtomatlashtirilgan jarayonlarni amalga oshirish, uni innovatsion usullar va vositalar yordamida loyihalash hamda real sharoitlarda qo‘llashni o‘rganadi. Tizimning asosiy maqsadi o‘simlikning ildiz zonasida normal sharoitlarni ta'minlash, suv va o‘g‘itlarni optimal dozalarda va past oqim tezligida etkazib berishdir. Past bosimda gidravlik tizimni optimal nazorat qilish taklif etiladi.

Kalit so‘zlar: Issiqxona, gidravlik tizim, tomchilatib sug‘orish, aqlli o‘lchash, moslashuvchan boshqaruv, ko‘p sensorli tizimlar

1.INTRODUCTION.

Drip irrigation in greenhouses is considered the optimal irrigation method for growing plants in modern agriculture because it is reliable, efficient, and widely used. The technology provides controlled application of water and nutrients directly to the root zone of plants through a network of pipes, emitters, filters, and control devices. The growing global demand for sustainable agriculture to increase productivity by saving water has accelerated the development of smart drip irrigation systems for greenhouse cultivation [1], [2].

Tomatoes, cucumbers, peppers, eggplants, and other melons are considered the most economically important field in the world, and greenhouse horticulture is being developed because they are daily food products. Productivity and quality in this field depend largely on the precise regulation of the moisture content of the "soil" - the root zone of plants, nutrient concentration, air humidity, and temperature. Traditional irrigation methods often lead to excessive water consumption, uneven wetting, leaching of nutrients, and the development of diseases. Drip irrigation minimizes these deficiencies by delivering water in measured doses according to the physiological requirements of the plant [3], [4].

2.GENERAL PRINCIPLES OF DRIP IRRIGATION.

The basic principle of drip irrigation in greenhouses is to deliver a gradual and localized application of water to the root zone of plants in the form of droplets or low-velocity micro-streams of water containing optimal doses of fertilizers.

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The water is transported under low pressure through a hydraulic system and discharged through emitters located near the root ball of each plant [5].

A typical greenhouse drip irrigation system consists of the following components:

– Water source and pumping unit;
– Filtration system;
– Main and side pipelines;
– Drip emitters or drip tapes;
– Fertilizer unit;
– Pressure regulators;
– Sensors and controllers;
– Monitoring and automation subsystem [6].

Functional Diagram of Drip Irrigation System

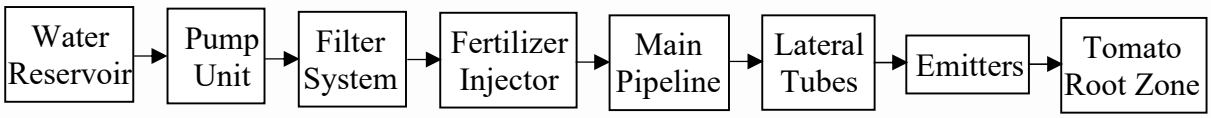


Fig. 1. Functional Diagram of a Drip Irrigation System

The principle of local irrigation significantly reduces the amount of evaporation (losses), allowing to maintain moisture in the active rhizosphere of plants at the exact, required level [7].

2. Water Requirements of Greenhouse Plants

Due to the intensive transpiration of vegetables or berries grown in greenhouses and the required climatic conditions, the constant humidity of the environment, along with the irrigation zone, is regulated. Thus, the water requirement regime depends on the following parameters:

– Solar radiation;
– Air temperature;
– Relative humidity;
– Plant growth stage;
– Soil or substrate properties;
– Greenhouse ventilation conditions [8].

During vegetative development, plants require moderate watering, while the flowering and fruiting stages require a higher water supply. Excessive watering leads to root hypoxia, fungal diseases, and nutrient imbalance. Insufficient watering regime leads to small fruit size, reduced yield and quality [9].

The crop evapotranspiration approach is commonly used to determine irrigation scheduling:

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$$ET_c = K_c \times ET_0$$

where:

ET_c – crop evapotranspiration;

K_c - crop coefficient;

ET_0 - reference evapotranspiration.

This equation is fundamental for calculating the required irrigation water volume in greenhouse tomato cultivation [10].

3. SOIL MOISTURE CONTROL AND IRRIGATION SCHEDULING.

Efficient drip irrigation requires continuous monitoring of soil moisture. In greenhouse tomato production, irrigation scheduling is often based on:

- Soil moisture sensors;
- Tensiometers;
- Climatic data;
- Evapotranspiration models;
- Plant stress indicators [11].

Modern automated systems employ intelligent controllers capable of activating irrigation according to sensor feedback. The optimal soil moisture range for greenhouse tomatoes generally varies between 70–85% of field capacity [12].

Table 1.

Irrigation Scheduling Approaches

Method	Principle	Advantages
Time-based irrigation	Irrigation at fixed intervals	Simple implementation
Sensor-based irrigation	Real-time soil moisture monitoring	High efficiency
Climate-based irrigation	Based on evapotranspiration	Water saving
Adaptive irrigation	AI and feedback algorithms	Precision management

Adaptive irrigation systems significantly improve water use efficiency and reduce energy consumption in greenhouse operations [13].

4. FERTIGATION IN DRIP IRRIGATION SYSTEMS.

One of the most important advantages of drip irrigation is the possibility of fertigation - simultaneous application of fertilizers with irrigation water.

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Fertigation enables accurate nutrient dosing and uniform nutrient distribution in the root zone [14].

The following nutrients are essential for greenhouse tomato cultivation:

- Nitrogen (N);
- Phosphorus (P);
- Potassium (K);
- Calcium (Ca);
- Magnesium (Mg);
- Micronutrients [15].

Nutrient concentration is typically regulated using electrical conductivity (EC) and pH measurements. Excessive fertilizer concentration may increase soil salinity and negatively affect plant growth [16].

5. HYDRAULIC PRINCIPLES OF DRIP SYSTEMS.

The hydraulic performance of drip irrigation systems is determined by pressure distribution, emitter discharge uniformity, and pipeline characteristics. The emitter flow rate is commonly expressed as:

$$q = kH^x$$

where:

- q - emitter discharge;
- H - pressure head;
- k, x - emitter coefficients.

Pressure-compensating emitters are frequently used in greenhouse applications because they maintain stable flow rates under varying pressure conditions [17].

Uniformity of irrigation directly influences tomato growth consistency and crop yield. Therefore, hydraulic design must minimize pressure losses throughout the irrigation network [18].

6. AUTOMATION AND SMART IRRIGATION CONTROL.

Modern greenhouse automation technologies are increasingly integrating drip irrigation systems. Smart irrigation control includes:

- Wireless sensor networks;
- Internet of Things (IoT) devices;
- PLC and microcontroller systems;
- Artificial intelligence algorithms;
- Cloud-based monitoring platforms [19].

A generalized algorithm for automated irrigation is proposed as follows:

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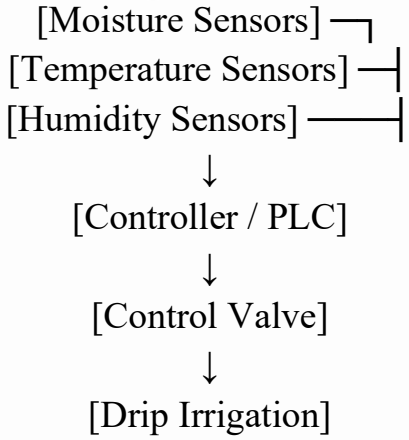


Fig. 2. Automated irrigation algorithm

These technologies allow real-time optimization of irrigation according to environmental conditions and plant physiological responses [20].

Advantages of Drip Irrigation System:

• High water use efficiency;
• Reduced evaporation loss;
• Improved fertilizer utilization;
• Reduced weed growth;
• Reduced disease incidence;
• Increased yield and quality [21].

Limitations

• Emitter clogging;
• Initial installation cost;
• Need for filtration service;
• Salt accumulation near rain areas;
• Dependence on technical management [22].

Emitter clogging remains one of the main operational problems in drip systems used in greenhouses. Our research has achieved a positive solution to this problem. In this case, the direction of the liquid transfer, which is a mixture of water and fertilizer, in a closed irrigation pipe is periodically changed. That is, the liquid is injected clockwise for the first time, and counterclockwise for the second time. Thus, this process is carried out periodically, and the problem is solved at a high level. Proper filtration and periodic cleaning operations are considered necessary to maintain the reliability of the system [23].

Environmental and Economic Importance:

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Drip irrigation contributes significantly to sustainable greenhouse farming by conserving water resources and reducing environmental pollution caused by fertilizer leaching [24-27].

Studies have shown that drip irrigation systems can increase tomato yields by 20–50% and reduce water consumption by 30–60% compared to traditional irrigation methods [25].

The integration of renewable energy sources and intelligent control algorithms further increases the sustainability and economic efficiency of greenhouse production systems [26, 27].

CONCLUSION.

The drip irrigation method and system is a highly effective and technologically advanced method for cultivating agricultural crops in greenhouses. Its main principles are based on localized water delivery, precise moisture control, fertilization, hydraulic stability and intelligent automation. The application of multisensor technologies and adaptive control systems significantly increases water efficiency, productivity and environmental sustainability.

Future developments in the field of greenhouse drip irrigation are expected to focus on artificial intelligence, predictive irrigation algorithms, digital twins and autonomous monitoring systems for precision agriculture.

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