# An Assessment of Control Methods in Closed-Loop Agriculture Systems

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**Abstract**

Climate change and a growing global population pose ongoing threats to critical resources. As resources required by the agriculture sector continue to diminish, it is critical to leverage the emerging technologies and new solutions within the sector. New cultivation practices have emerged over the years, allowing food to be grown within urban areas. Greenhouses are versatile in the resources needed for their operation, as well as the foods that can be grown. While greenhouses provide a potential for a more constant food supply, there is a lack of optimization between the components. There are benefits to having modular components of a greenhouse, allowing for adjustments or repairs to singular pieces. However, there is inefficiency in the entire system, since each component functions without considering the others. To improve greenhouse efficiency, a closed-loop system can be introduced. A greenhouse is a closed system, and by repurposing, reusing, and recirculating resources, a greenhouse can evolve to have a closed-loop system. This enables the components of a system to share resources more effectively, communicate any systems changes that are required, and minimize waste outputs.

This research explores the current technology in the space of agriculture and computer science to create a fully closed-loop system. The most noticeable system components are food waste, nutrient systems, water systems, growing media, and heating and energy. Not all components within a greenhouse can leverage the same artificial intelligence methods and techniques based on existing findings. There are methods in place that allow the components to interpret data gathered from the greenhouse and alter its operational patterns. There remains a lack in communicating this information to other aspects of the system to have it make informed data-driven decisions as well. One can optimize singular components thereby reducing resource reliance, to a certain threshold until it impacts the plant's development and yield. When all the systems components' resource needs and outputs converge the functionality of the system can be optimized to utilize resources at a higher efficiency. Results are indicative of very siloed and isolated research, exploring closed-loop systems within greenhouses, but not leveraging its full capabilities.

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## Introduction

- Producers are facing challenges, including climate change, water scarcity and population growth.[4]
- The global population is projected to reach 9.9 billion by 2050.[12]
- As urbanization continues to compromise farmland, alternative approaches must be explored.[2]
- There is a lack of optimization between systems.

## Objectives

- Identify gaps in research concerning closed-loop agriculture systems.
- Identifying data availability to mobilize system optimization techniques.

## Methodology

- Meta-research approach utilizing a text-mining approach.
- Keyword utilization for search on Web of Science, including; closed-loop, food, greenhouse, and agriculture.

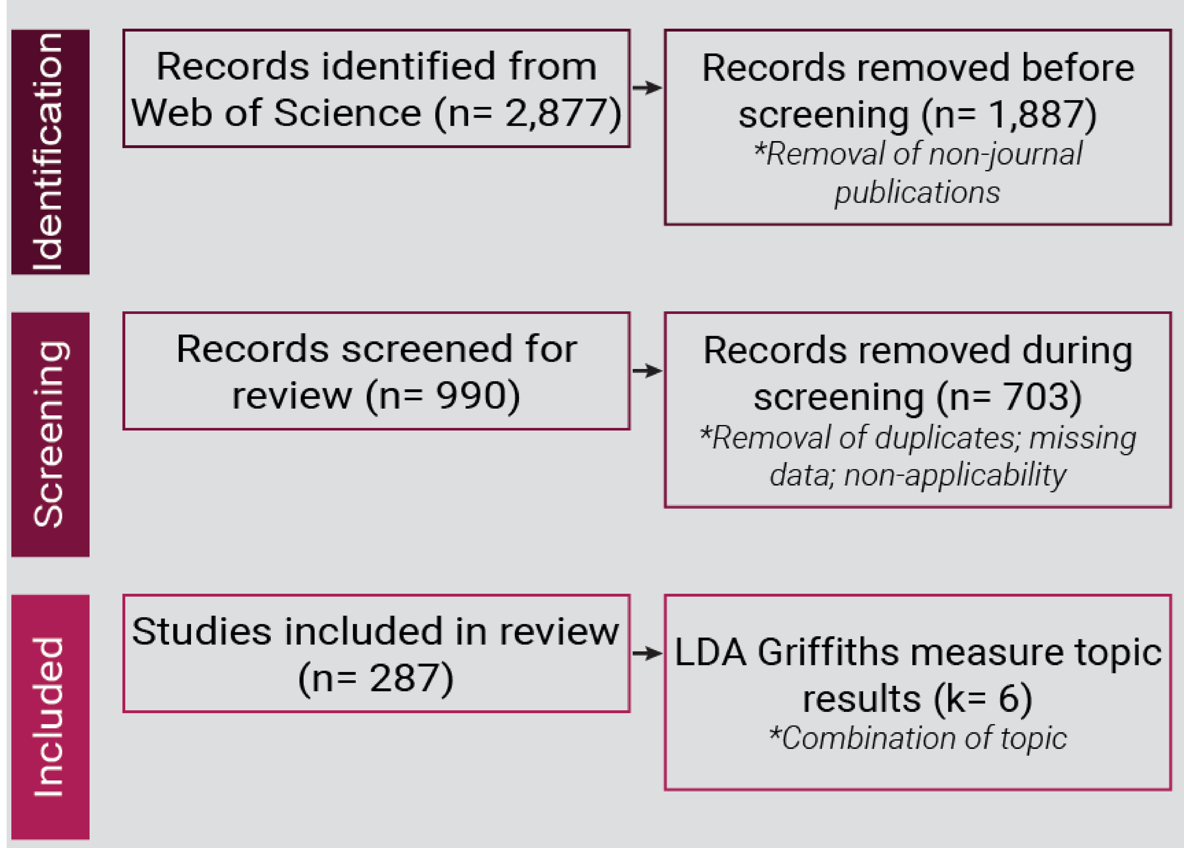


**Figure 1.** PRISMA[7], as applied in this systematic review paper, indicates the number of studies included in the review.

## Learn More About This Work

The preprint of Closed-Loop Agriculture System Meta-Research Using Text Mining is available by scanning the QR code.

## Results

- Greenhouses are influenced and impacted by biological and physiological subsystems.[5]
  - The plant being grown is part of the biological subsystems.
  - The infrastructure is part of the physiological subsystems.
- Growing conditions must be maintained and monitored for optimal plant and crop production while minimizing resource needs.[10]

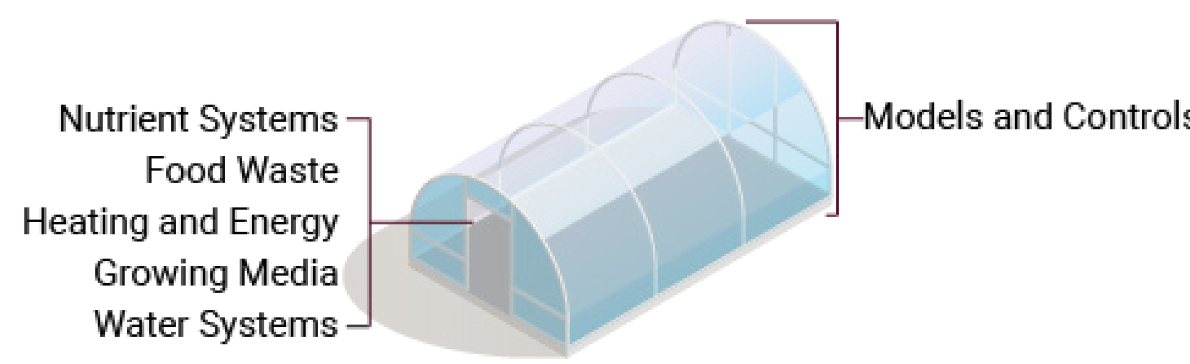


**Figure 2.** Topic modelling yielded six topics of value for further assessment. The topic 'Models and Controls' influences and impacts much of the remaining topics and encompasses aspects of the entire greenhouse system.

### ENERGY UTILIZATION & HEATING

- Neural networks allow for performance testing and altering system parameters.[5]
  - Energy utilization and heating, which can be controlled with various algorithms, can be assessed in this manner.
- Energy can be conserved and reallocated to various subsystems in a greenhouse using fuzzy adaptive controls.[9]
  - Various control laws exist in a greenhouse system, including heating, fogging and $CO_2$ injection, which, when measured, can be used to determine energy utilization.
  - Input and output measurements are collected by controllers and actuators in order to make informed decisions on energy needs and demands.
- Energy conservation can be achieved by selectively supplementing lighting for precise areas within a greenhouse.[6]
  - Neural network-based modelling allows for the identification of plants that require wavelengths.

### CLIMATE CONDITIONS

- Alternatives to user-controlled temperature and humidity control methods have been tested for effectiveness.[3]
  - Methods include Bayesian networks, fuzzy adaptive controls, and proportional-integral-derivative controls.
- The application of a Bayesian network provides effective information through probabilistic outcomes concerning climate conditions.[3]
  - This can effectively inform user controls if desired within the system.
- System modularity can be retained using parameter self-tuning proportional–integral–derivative (PID) controls if desired.[11]
  - Favorable approach allowing closed-loop system principles and practices to be retained while enabling flexibility to boost select aspects when needed.

### GROWING CONDITIONS

- Irrigation system performance can be improved through the application of a closed-loop system. [8]
  - A comparative study indicated an event error of less than 2L/m$^2$ for the water introduced to the system using the closed-loop irrigation method over the open-loop irrigation method.
- Dynamic simulation model-driven approaches for irrigation systems indicate a high correlation efficiency between the model prediction level and observed experimentation values.[13]
  - Communication nodes carry out decisions made by the dynamic simulation, which is informed by a larger wireless sensor network and has been applied to drip irrigation pipes and ventilation equipment.
- The application of electrical conductivity sensors in closed-loop soil and soilless growing cultures allows for the predetermination of a plant's future nutrient needs.[1]
  - Nutrients are most commonly introduced and maintained through water within a greenhouse agriculture system.

## Conclusion

- A closed-loop system is favourable to optimizing the interactions and relationships between various subsystems.
- The applications of models and controls allow for a closed-loop system approach.

## Future Works

I. Connecting research and industry application
II. Energy dependency and other critical requirements
III. Criteria to select the appropriate soil or soilless growing environment
IV. The integration and resilience of a closed-loop system composed of many individual modules

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