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A meta-analysis: Food production and vegetable crop yields of hydroponics

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Highlights

- The productivity of hydroponic growing systems depends on crop types.
- There is no best growing orientation in hydroponics, it depends on the crop types.
- The crop yields of the controlled environment are significantly higher than the open-air setup.

Abstract

Hydroponics is a soilless farming method that can contribute to meeting the global food demand, improving food sustainability as well as ensuring food availability in a novel high efficiency yet low maintenance way. In this global meta-analysis, the crop yields of hydroponic cultivation were quantified and the differences in yields for distinct farming systems as in hydroponic vs. soil-based systems, farming orientations as in vertical vs. horizontal farming and environments as in controlled environment vs. open-air agriculture, were discussed. 499 observations were extracted from 68 papers that discussed hydroponic crop yields. The most studied vegetable crops were “Lettuce and chicory”. The greatest difference in crop productivity between hydroponics and soil-based agriculture was observed in "Spinach," with yields of 2.7 kg m^{-2} $year^{-1}$ for hydroponics compared to 16.35 kg m^{-2} $year^{-1}$ for soil-based agriculture. The result showed that the productivity of the growing systems varied between crop categories. The impact of the growing orientation was significant for "Lettuce & chicory" and "Vegetables, fresh nes", but there was no clear pattern indicating the best growing orientation overall. The crop yields of the controlled environment were significantly higher than the open-air setup; it had a significant effect on “Anise, badian, fennel, coriander”, “Cabbage & other brassicas”, “Lettuce & chicory” and “Vegetables, fresh nes”. This meta-analysis helps in quantifying the globally relevant crop yields of hydroponic farming systems, seeks to provide more solid evidence of the crop yields for hydroponic agriculture and determines the better hydroponic growing environment.

Introduction

The disruption of food system resilience and the declining global food security due to climate change and environmental degradation lie at the center of a nexus of global concerns. Agricultural productivity is likely to become harder to meet the escalating food demands associated with the growing world's population, which is expected to expand to 9.5 billion people by the year 2050 (Langelaan and Silva, 2013). To address this problem, the high crop yield of hydroponic cultivation is expected to increase the compound annual growth rate by 20.7% from 2021 to 2028 (Hydroponics Market, 2021). Additionally, the implementation of the Internet of things in hydroponic farming offers farmers various methods to closely monitor and manage their crops with the aid of sensors, microcontrollers, website platforms, and mobile applications automatically.

Soil-based agriculture provides a range of unique benefits that are rooted in our connection to the natural world. For example, microbes like archaea exist naturally in soil, which can help to improve plant growth via auxin biosynthesis, boosting nutrient supply to the plants, and providing protection against abiotic stress (Chowetal., 2022). Microbial consortia were also observed to exert potential effect on plant development by the mitigation of several stressors such as salinity and heavy metals faced in agriculture in general and leafy vegetable crops in specific (Širić etal., 2022; Chaudharyetal., 2023; Sardaretal., 2023). However, in recent decades, soil-based farming is gradually replaced by soilless farming systems as it can cause numerous negative impacts on the environment. Monocropping, land expansion for agriculture associated with excessive mineral fertilizing can result in biodiversity loss, water pollution, soil quality deterioration and emission of greenhouse gasses (Dissanayakeand Chandrajith,2009; Smithetal., 2016; Alietal., 2019; Huygensetal., 2019). It is predicted that between 21% and 37% of total greenhouse gas emissions contributed from the unsustainable geoponic practices are linked to the unstable, unequal, and unsustainable global food system (Payenetal., 2022). Some of these environmental impacts are not unique to just soiled-based agriculture, it is also practiced in the soilless agriculture, for example, the use of pesticides to minimize pests problems.

Hydroponics refers to soilless farming methods using water-based nutrient solutions (Grewaletal., 2011; Wortman,2015; Shresthaand Dunn,2017). Hydroponic cultivation has been suggested as one of the potential solutions to the issue of food insecurity at the global level.

Hydroponic systems play an important role in relieving the rising threat of global hunger and a world growth of 18.8% from 2017 to 2023 is expected, corresponding to a global market of USD490.50 million by 2023 (Aires,2018). This advanced system with a controlled growth environment offers the growers the ability to produce continuous crops in a shorter growing period, requires smaller space, and has higher crop productivity, regardless of the climate, soil quality or availability of cultivable land (Sharmaetal., 2018; Khanetal., 2021). Hydroponic farming can produce fresh and quality food domestically for regions with extreme droughts or poor soil conditions, where leafy green vegetables are often difficult to access. Fully controlled hydroponic farms do not rely on pesticides and have a much smaller reliance on fertilizers to grow maximum crop yields. This system helps to produce more environmental-friendly fresh vegetables at minimal waste levels. Lettuce is the most hydroponically grown crop and about 99% of its leaves are healthy and valid, and can be sold for a price that is about 40% more

expensive than lettuce planted conventionally (Aires,2018). Although the cost of production of hydroponically grown lettuces is higher, people are still willing to pay for the premium due to the better quality of the vegetables and the increased awareness of Sustainable Development Goals (SDGs). Several studies proved that hydroponics could contribute to global efforts in mitigating environmental deterioration, increasing food stability and most importantly, enhancing food sustainability (Treftz and Omaye,2016; Khan,2018; Martin and Molin,2019).

It is essential to have a piece of synthesized current information about hydroponic farming. Compared to the conventional soil-based farming system, public's comprehension of hydroponic agriculture is in its relative infancy. To the best of our knowledge, there is no global assessment evaluating vegetable crop productivity and yields of hydroponics. The meta-analysis presented by Ayipio et al.(2019) reported the comparison of the crop productivity and yields between aquaponics and hydroponics, but does not focus on the differences between soilless and soil-based farming methods. Therefore, there is no direct comparison to show how efficient the hydroponic farming method is in boosting crop yields.

The assessment of the agronomic suitability of a hydroponic system, how its food production could meet consumers' rising demand at the global level and what types of vegetable can be planted remains relatively unspecified. There is a need to enhance our knowledge on the potential of hydroponics for food production so that it can become more popular and common in the world and eventually contribute to alleviating the global issue of food insecurity.

In this paper, the food productivity of hydroponic systems was assessed by estimating global values of vegetable crop yields obtained from the literature. The research questions (RQs) below were tried to be addressed by providing sufficient globally relevant evidence for the crop yields of the hydroponic system:

1) What types of vegetable crops are more frequently planted using a hydroponic system?

2) How does the crop yield of hydroponic agriculture compare with conventional soil-based agriculture?

3) Is vertical or horizontal farming orientation of a hydroponic system more efficient?

4) Does hydroponic controlled environment agriculture perform better than hydroponic open-air agriculture?

Answering the questions above would contribute to the future research about hydroponic farming methods to create a resilient and sustainable food system with minimal waste produced. Furthermore, this paper served the purpose of identifying the hydroponic growing agriculture systems that have the highest vegetable crop yields to shape the future agriculture practice and research.

Section snippets

Data collection

In this study, reliable sources of data in the form of scientific articles, conference proceedings and academic journals from trusted research institutions, universities, and commercially viable facilities have been analyzed and reviewed in February 2023, to identify peer-reviewed publications reporting vegetable crop yields of hydroponics at the global level. The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) system was referred to and followed in this research…

General findings

68 publications were included in this research study, their reported locations are shown in Fig.2. There were 499 observations of hydroponic agriculture crop yields from these 68 publications. Europe had the highest number of included studies (n=203), followed by South America (n=97), Asia (n=91), North America (n=89), Australia (n=11) and Africa (n=8). The top 5 countries were United States (n=61), Spain (n=57), Italy (n=55), China (n=32) and Japan (n=29). 65% of the…

Discussion

To the best of our knowledge, there are a few meta-analyses which are related to this topic, but each of them focuses on different areas and scopes. Firstly, Ayipio et al. (2019) compared the crop yields of aquaponics and hydroponics. However, the exact crop yields for each crop were not quantified and the difference was statistically insignificant to be analyzed due to the limited number of observations (n=50) obtained from 22 publications.

Other studies by Dorr et al. (2021) and …

Conclusion

The main objective of this research was to assess and compare the performance of hydroponic and soil-based agriculture across different crop types and to study how the different growing systems affect the crop yields of hydroponics. It was discovered that a wide range of vegetable crops were grown hydroponically. In the literature search, the crop category of “Lettuce & chicory” was studied the most.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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