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Urban vegetable production in Beijing, China: current progress, sustainability, and challenges

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Urbanization in China has entered a stage of accelerated development that is accompanied by a range of issues concerning resource, ecological and society. Urban vegetable production (UVP), an important part of urban agriculture, has the potential to be an effective countermeasure for dealing with these problems. Here, we review the current state of UVP with its related technology and equipment, and show the major models of UVP in China with three representative implementation cases in Beijing. Through this review, we found the impact of UVP on urban vegetable supply should not be underestimated, while it is still considered as an urban entertainment by public now. Moreover, UVP extension is still limited when compared with China's urbanization process. We analyze the possible reasons that restrict the development of UVP and give corresponding suggestions to improve it. Considering the scale of urbanization in China, and the potential contribution of UVP to food supply, environmental sustainability and social harmony, there is still much room for UVP development, which will bring opportunities and challenges to the government and scientific researchers.

KEYWORDS

urban agriculture, vegetable production, soilless culture, recycling agriculture, horticulture

Introduction

With the intensification of industrialization and urbanization, the population living in urban areas is expected to increase worldwide by approximately 68% by 2050 (FAO, 2017; DESA, 2018). China is in the process of rapid urbanization, with the urbanization rate to reach 65% by the end of 2021 (National Bureau of statistics of China, 2021). Accompanied by huge development potential and market space, the acceleration of urbanization processes also poses challenges for urban development, including a range of issues in modern cities, such as food shortages, ecological degradation, and more people with busy lives and high-stress jobs. Moreover, urban expansion would result in a 1.8 to 2.4% loss of global croplands (Bren d'Amour et al., 2017). According to the Food and Agriculture Organization (FAO), food security cannot rely solely on traditional rural production, as arable land is decreasing in most developed countries (Montanarella et al., 2015).

Against the background of urbanization, more attention has been paid to urban agriculture (UA), which can meet part of the food demand and has additional functions, such as ecological, entertainment, and demonstration functions (Zhong et al., 2020). As an important part of UA, urban vegetable production (UVP) has become popular in cities because of its simplicity, ease of operation, and diverse functions, including self-sufficiency, environmental friendliness, and leisure and relaxation. Through UVP, at least part of the vegetable supply can be guaranteed, especially in special periods (such as wars, plagues, and geological disasters), providing timely assistance for urban residents.

At the global level, a growing urban population produces various issues related to resource efficiency and massive flows of agricultural products from rural areas to cities, which cause pollution and traffic congestion (Sanyé-Mengual et al., 2015; Caldeira et al., 2019). Growing vegetables at home partially solves the problem of long-distance vegetable transportation in an environmentally friendly manner. Moreover, the combination of UVP and resource-recycling technologies (e.g., kitchen waste compost) will develop more resilient cities that maintain a sustainable food supply with minimum transport and zero waste.

In recent years, UVP has become popular in China due to the acceleration of urbanization and the improvement of living standards. Unlike other countries, the development of UVP in China prefers to emphasize high efficiency due to limited space and the growing population in urban areas. Thus, it requires constant progress in UVP technology, facilities, and models to promote the development of UA. However, in contrast to the ecological and social roles of UA, little attention has been paid to the status of its technology and application. This study aims to introduce UVP technology, equipment, and their application in China. It will provide significant insight into developing new technologies and production that may be more suitable for UVP.

Current progress and sustainability

In urban horticulture, virtually all plants are grown with soilless cultivation to avoid soil-borne diseases and continuous cropping obstacles (Paulitz, 1997). Soilless culture has high water and fertilizer efficiency, which reduce labor intensity and can be carried out in all places unsuitable for agricultural cultivation. Substrate culture and hydroponics are the most used type of soilless culture in UVP, which have been proved to improve uniformity in the weight, size, and texture of vegetables compared to those grown in soil (San Bautista et al., 2005; Gruda, 2008; Guilherme et al., 2015; Palencia et al., 2016). Substrate culture has a wider application range because of its simple facilities and easy cultivation techniques, while it also brings problems to urban planting, such as the treatment of waste substrate and transportation. Hydroponics requires less water and fertilizer input as the nutrient solution can be recirculated for an extended period (Wada, 2019). As the efficient hydroponic systems, the nutrient film technique (NFT) and deep-flow technique (DFT) are used frequently in urban farms (Figure 1).

The traditional irrigation approach in soilless culture is an open system (non-circulating), which is similar to soil culture discharging surplus water and nutrients (Figure 2A). Although it requires lower investment, the open system is being phased out because of water and fertilizer losses and environmental pollution. Instead, closed systems (circulating), that recycle excess water and nutrients by adding return pipe fittings have been developed (Figure 2B).

According to different locations, scales and types of vegetable, various equipment and planting systems suitable for urban vegetable planting have been developed. The vertical systems (see Supplementary Figure S1) that is popular for families, schools, offices, and restaurants as it is not only an art installation but can also maximize the available growing area in a limited space (Tyler, 2018). These kinds of systems mainly used natural light with low cost and relatively easy technology, while they were not suitable for indoor planting and were greatly affected by the climate and environment. Supplementary lighting system is indispensable for indoor planting, such as balcony gardens and container farms, which all require appropriate artificial light to replace sunlight to support vegetable production. High-pressure sodium lamps (HPS) are often used for winter greenhouse cultivations in northern latitudes as they generate high amounts of radiant heat. While these light sources have high energy consumption and short lifetimes, which will increase the cost of planting (Bantis et al., 2018). For the past few years, the light-emitting diodes (LEDs) as alternative light sources for use in greenhouse were widely welcomed since they convert electricity to light up to 50% more efficiently than HPS and have more accurate spectral composition (Särkkä et al., 2017). With the progress of spectral regulation and intelligent control technology, indoor gardening equipment has gradually increased. For example, a multilayer cabinet planter can realize the circular cultivation of vegetables indoors (see Supplementary Figure S2). Moreover, there are various mini-vegetable-planting systems suitable for placement on the table; however, they are generally not used for vegetable production, but rather for interior decoration and education in school (see Supplementary Figure S3).

For industrial-scale peri-urban farms, the existing methods of vegetable production are not that effective when it comes to labor requirements, water and energy conservation, and remote management. Intelligent technologies based on wireless sensor networks and machine learning, such as the Internet of Things (IoT) and computer vision, have been introduced into smart agriculture (Kamilaris and Prenafeta-Boldú, 2018). IoT interrelates light, CO_2, humidity, temperature, water, and nutrients connected to the Internet to automatically monitor data (Viani, 2016). It can decide what actions should begin or stop depending on cultivation conditions and allow planters to monitor and control the farm remotely (Komol et al., 2019). In China, this type of intelligent equipment has been introduced into urban agricultural production, while it has not been widely used due to its large investment cost.

UVP cases in Beijing

Case 1: weekend garden

Sanyuan Farm, in the northeast of the Haidian district of Beijing, is approximately 10 km from downtown. It covers an area of around 33.33 ha, of which 17.33 ha is divided into more than 2000 plots and rented to nearby residents as family vegetable gardens where families can manage their gardens every weekend (see Supplementary Figure S4). The farm encourages people to adopt a resource-efficient urban agriculture model through kitchen waste compost, which turns waste into fertilizer and simultaneously provides a healthy, happy lifestyle.

Case 2: paper-based sprouts garden

Sprouts are tender immature greens with two fully developed cotyledon leaves produced from the seeds of vegetables and herbs (Xiao et al., 2012). In past decades, with the increasing interest in

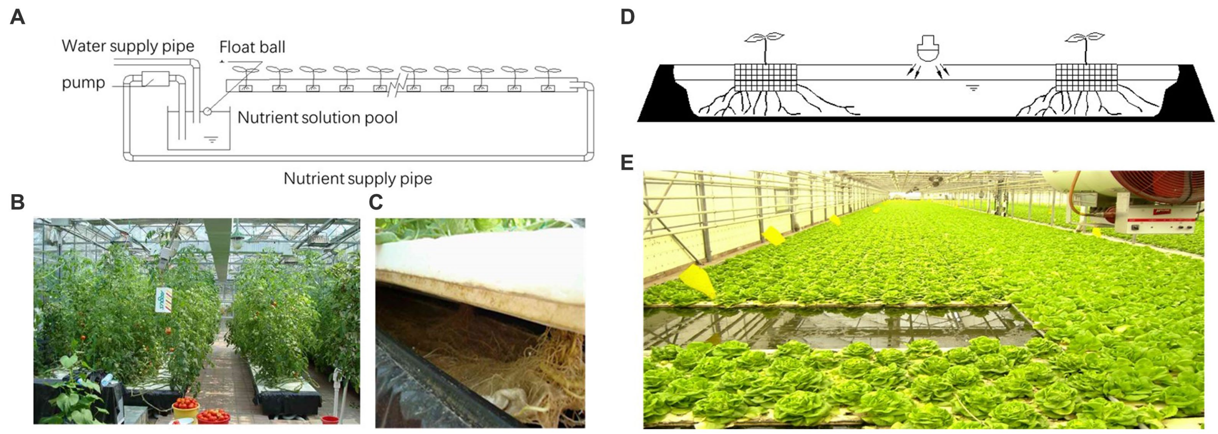

FIGURE 1
Hydroponic systems. **(A)**, Sketch of NFT. **(B)** and **(C)**, the picture of plants **(B)** and their roots planted in NFT **(C)**. **(D)**, Sketch of DFT. **(E)**, Lettuce planted in DFT.

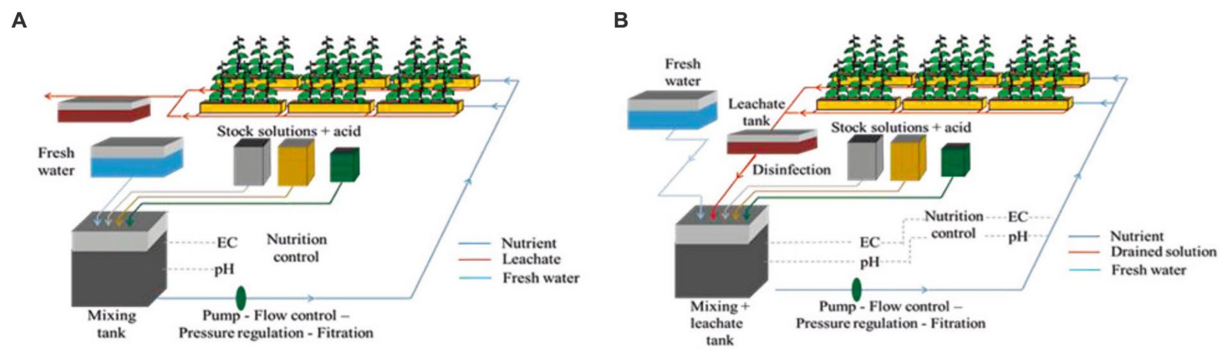

FIGURE 2
Open-loop **(A)** and closed-loop **(B)** system of soilless culture. (Savvas et al., 2013).

fresh, organic, nutritional food, sprouts have received more attention from urban residents in China.

Wangjiayuan Hutong, a typical 'old Beijing' community, is located in the Dongcheng district in Beijing. Hundreds of residents reside here, especially aged citizens, and enjoy sprouts planting. The sprouts are grown on a piece of absorbent paper with regular watering to maintain a moist environment for approximately 10–15 days. Various grow plates and racks can be selected according to the spatial layout of their rooms (see Supplementary Figure S5). A large variety of sprouts, including soybean, pea, cowpea, radish, sunflower, and buckwheat sprouts, are popular among urban residents.

Case 3: aquaponics system with high efficient and zero waste

To pursue zero pollution and carbon neutrality to a greater extent, an upgraded system of hydroponics called aquaponics has emerged. At Sanyuan Farm, there is also a running aquaponics system (see Supplementary Figure S6). The aquaculture water from the container will overflow into the planting trough, where it can be purified by the cooperation of plants and bacteria on the surface of the substrate. The purified water will be pumped back into the aquaculture container again. In a balanced aquaponics system, two products are produced simultaneously with almost the same amount of resource input (Goddek and Körner, 2019). As an efficient and eco-friendly agricultural technology, aquaponics has been considered promising for helping urban areas meet their food needs.

Hurdles and future directions

So far, UVP is still considered as an urban entertainment, its impact on urban vegetable supply is underestimated. To display its potential capacity to local food supply, we collect the annual yield data through growing vegetables with UVP planting systems mentioned in this paper. It can be seen from Supplementary Table S1 that about 100 kg/year of vegetables can be produced even using the area of 0.2 m^2. According to the Dietary guidelines for Chinese Residents, the daily consumption of vegetables should be more than 300 g/capita, which is more than 110 kg/year/capita. Thus, even the domestic planting systems can partially meet the vegetable demand of urban residents.

However, a range of factors, as listed below, restrict UVP development. (1) UVP is not a mini-version of traditional agricultural production which should not be copied completely for urban vegetable production. The lack of UVP cultivation technology leads to a low survival rate, low yield, and poor quality, which forces many urban residents to abandon vegetable production. (2) Excessive energy consumption is caused by massive water demand and electricity input for heating, lighting, and water pumping, which are essential for indoor planting. (3) Current urban planning without agricultural land can be attributed to political and legal barriers that restrict urban land access for farming.

To improve the sustainable development of self-sufficient vegetable production in urban areas, we make the following practical suggestions: (1) Pay more attention on professional researches including breeding, the development of intelligent planter, culture substrate and fertilizer product according to the characteristic and demand of UVP. (2) Promote interdisciplinary integration to contribute to the development of energy-saving and environment-friendly urban agriculture. For instance, to reduce water consumption in UVP, roof rainwater harvesting can be combined with an urban agriculture irrigation system. Moreover, kitchen waste compost and solar energy storage, which can be used for greenhouses in the cold season, is also a resource-efficient practice. Lastly, (3) improve government support for UVP development from policies to financial, such as more investment for UVP researches, the adjustment of urban planning and space utilization policies.

Conclusion

The present paper provides not only a picture of the current state of UVP implementation by summarizing existing technologies, equipment, and their application but also some suggestions about the hurdles and future direction of UVP. Although UVP has been paid an increased attention in Chinese urban areas, it is still far away from being an industry when compared with China's urbanization scale. Additionally, the contribution of UVP to urban vegetable supply for urban residents should not be ignored as its high productive potential. Considering its economic, ecological and social benefits, it is necessary to extensively develop UVP in China and even around the world.

Author contributions

WJ and HY conceived the idea. QL contributed to the writing of the article. ZY, ML, GZ, TL, and YL contributed to the review, proofreading, and finalizing the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

ZY was employed by Beijing Da Di Pu Yuan Agricultural Technology Co., LTD. ML was employed by Beijing Photon Science & Technology Co., LTD. GZ was employed by Beijing Green Valley Sprout Co., LTD.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1191561/full#supplementary-material

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