Originally published as:

Pradhan, P., Callaghan, M., Hu, Y., Dahal, K., Hunecke, C., Reußwig, F., Lotze-Campen, H., Kropp, J. P. (2023): A systematic review highlights that there are multiple benefits of urban agriculture besides food. - Global Food Security, 38, 100700.

DOI: https://doi.org/10.1016/j.gfs.2023.100700

A systematic review highlighting multiple benefits of urban agriculture besides food

Prajal Pradhan[a,b,*], Max Callaghan[c,d], Yuanchao Hu[e], Kshitij Dahal[f], Claudia Hunecke[a], Fritz Reusswig[a], Hermann Lotze-Campen[a,g], Jürgen P. Kropp[a,b,h]

[a] *Potsdam Institute for Climate Impact Research – PIK, Member of Leibniz Association, Potsdam, Germany*
[b] *Bauhaus Earth, Berlin, Germany*
[c] *Mercator Research Institute on Global Commons and Climate Change, Berlin, Germany*
[d] *Priestley International Centre for Climate, University of Leeds, Leeds, UK*
[e] *School of Resource and Environmental Sciences, Wuhan University, Wuhan, China*
[f] *School of Sustainable Engineering and the Built Environment, Arizona State University, Arizona, USA*
[g] *Department of Agricultural Economics, Faculty of Life Sciences, Humboldt University of Berlin, Berlin, Germany*
[h] *Institute of Environmental Science and Geography, University of Potsdam, Potsdam, Germany*

[*] corresponding author: pradhan@pik-potsdam.de

A systematic review highlights that there are multiple benefits of urban agriculture besides food

Abstract

Urban agriculture, including peri-urban farming, can nourish around one billion city dwellers and provide multiple social, economic, and environmental benefits. However, these benefits depend on various factors and are debated. Therefore, we used machine learning to semi-automate a systematic review of the existing literature on urban agriculture. It started with around 76,000 records for initial screening based on a broad keyword search strategy. We applied the topic modeling approach to systematically understand various aspects of urban agriculture based on the full text of around 1450 relevant publications. Urban agriculture literature covers 14 topics, clustered into 11 themes related to urban agriculture forms, their multi-functionalities, and their underlying challenges. These forms are small-scale ground-based and building-integrated systems. The multi-functionalities include food, livelihoods, health benefits, social space, green infrastructure, biodiversity, and ecosystem services. Therefore, promoting urban agriculture requires accounting for its multi-functionalities, besides food provisioning, and encouraging efficient and sustainable practices.

Keywords: urban agriculture, topic model, systematic review, sustainability, ecosystem services, multi-functional

1. Introduction

Urban agriculture is a globally prevalent practice, which encompasses various forms of farming activities within urban areas and their surroundings (Graefe et al., 2019). They include traditional farming, allotment gardens, rooftop gardens, hydroponics, aquaponics, and indoor vertical farming. Broadly, they are ground-based or building-integrated with or without space conditioning (Goldstein et al., 2016b). Several studies highlight the potential contributions of urban agriculture to nourish urban residents from local (Costello et al., 2021; Hume et al., 2021; De Simone et al., 2023) to global (Martellozzo et al., 2014; Clinton et al., 2018a) scales. For example, Kriewald et al. (2019) showed that urban agriculture could nourish about one billion people, i.e., 30% of the total urban population. Martellozzo et al. (2014) highlighted that cultivating vegetables in one-third of the global urban areas can fulfil the urban population's vegetable demand. Berlin could produce up to 82% of its vegetable demand within the city, according to De Simone et al. (2023). Vegetables are an essential component of a healthy diet (Willett et al., 2019), which consumption is lower than the recommended value almost worldwide (Pradhan and Kropp, 2020; Harris et al., 2023). In this sense, current vegetable production can hardly meet the demand if the recommended intake level is achieved Dong et al. (2022). Urban agriculture might be an instrument to fill this gap Harris et al. (2023).

Urban agriculture, involving over 800 million people, is a pivotal aspect of the global food system (O'Sullivan et al., 2019). It constitutes a proportion of 5–10% of global food production (Clinton et al., 2018b), with a larger share in low- and middle-income countries, e.g., Zambia and Kenya, where 33% of households are involved (Davies et al., 2021a). Urban agriculture also provides multiple ecosystem services, amounting a value of $33 billion annually (Clinton et al., 2018b). These ecosystem services include food production of 100–180 million tonnes, energy savings of 14–15 billion kilowatt hours, nitrogen sequestration of 100,000–170,000 tonnes, and avoided stormwater runoff of 45–57 billion cubic meters annually. In an intensive urban agriculture scenario, the overall value of these services could reach as much as $80–160 billion annually (Clinton et al., 2018b).

Besides the services mentioned earlier, urban agriculture can yield diverse social, economic, and environmental benefits, including community development and educational opportunities (Mirzabaev et al., 2021; Clinton et al., 2018b). Nonetheless, the applicability of these benefits remains a topic of debate because they depend on various factors, e.g., region, seasons, and forms (Mbow et al., 2019). For example, urban agriculture contributes to climate change adaptation, e.g., reduced urban heat island effects (Li et al., 2014), and climate change mitigation, e.g., atmospheric nitrogen and carbon fixation (Beniston and Lal, 2012). However, extensive irrigation will consume a large share of residential water use. By promoting the regionalization of food systems, urban agriculture helps to reconnect urban residents with nature's cycles and reduce food transport emissions (Pradhan et al., 2020). One-fifth of food systems' emissions come from transport (Li et al., 2022), which matters for climate change mitigation (Pradhan, 2022). However, urban agriculture's overall emission reduction potential is also questioned, mainly due to space conditioning systems with intensive infrastructure and a high energy demand (Goldstein et al., 2016a; O'Sullivan et al., 2020). Nevertheless, these systems could improve energy efficiency and use renewable energy (Goldstein et al., 2016a; Van Delden et al., 2021).

Urban agriculture is one of the main economic activities of poor households in many low-income countries (Poulsen et al., 2015). Besides an income source, it can mitigate the impact of seasonal food consumption shocks. These social and economic benefits of urban agriculture are also equivocal because of their dependency on the region and the form of urban agriculture. For example, ground-based urban agriculture faces pressure from urban sprawl (Pradhan et al., 2014). Nevertheless, some metropolitan areas are also observing agriculture renaissances with an increased share of GDP from the agriculture sector (Rybski et al., 2021). Additionally, conditioned urban agriculture could mainly produce leafy vegetables and herbs, i.e., limited food commodities. Often these commodities, produced in conditioned urban agriculture, are expensive and beyond the reach of poor households (Al-Kodmany, 2018).

Informing these debates on the multi-functionality of urban agriculture requires an evidence synthesis from existing studies, e.g., based on a systematic review. So far, reviews of urban agriculture have focused on limited aspects. For example, Poulsen et al. (2015) and Warren et al. (2015) investigated urban agriculture contributions to income and food security. Goldstein et al.

(2016b) compared environmental benefits between urban and conventional agriculture. McCartney and Lefsrud (2018) reviewed studies on conditioned urban agriculture in extreme environments. Similarly, Al-Kodmany (2018) focused on vertical farms, requiring space conditioning. Appolloni et al. (2021) investigated worldwide cases of urban rooftop agriculture, i.e., building-integrated systems. Recently, Payen et al. (2022) conducted a meta-analysis on urban agriculture yields, and de Oliveira Alves and de Oliveira (2022) focused on economic, social, and environmental factors to commercialize urban agriculture. Nitya et al. (2022) assessed the geographical landscape of urban agriculture quantitatively and qualitatively. Still, a holistic and robust evidence synthesis on the multi-functionality of urban agriculture is missing, including their spatial and temporal dynamics.

This study aims to fill the above-highlighted gap by holistically understanding the multi-functionality of urban agriculture. A holistic understanding needs to be based on an extensive body of literature. Therefore, we attempt to cover most peer-reviewed publications on urban agriculture. Using these publications, we systematically categorize topics on urban agriculture and their spatial and temporal dynamics. Our topics articulate urban agriculture forms and their multi-functionalities, including their challenges. The next section describes our methodology, followed by the sections analyzing the topics and discussing the novelties of our study.

2. Methods

We conducted a literature analysis to understand the multi-functionality of urban agriculture, and it comprised two parts. The first was to systematically search for peer-reviewed publications, excluding grey literature, on urban agriculture and screen the relevant ones. We selected the relevant articles written in English and with PDFs available. Second, we applied a topic modeling approach to identify topics covered by these relevant publications.

2.1. Literature search and screening

We followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement (Page et al., 2021), the standard procedure, to search and screen literature (see Figure 1). We covered an extensive body of literature by applying a broad keyword search strategy instead of a narrow one. Mainly, we searched for literature with words "*urban* or city or cities" and "agricultur* or garden* or farm* or food" and "form* or type* or typolog* or class* or kind*" in the title, abstract, or keywords. We expected this search to return literature mentioning urban and agriculture and its type. Our search across the two well-established literature databases – Web of Science and Scopus, on 15.02.2022 resulted in around 76,000 records.

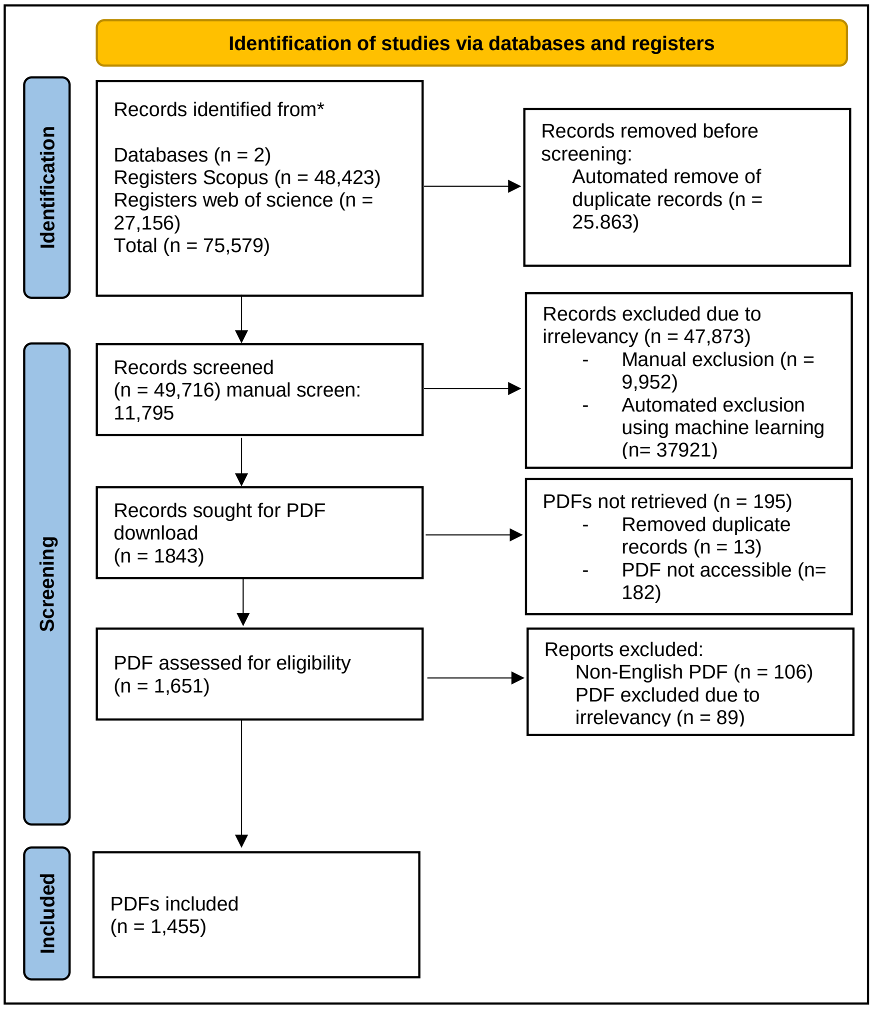

Figure 1: We followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement (Page et al., 2021) to identify the relevant literature from Scopus and Web of Science database for our study.

Screening relevant documents out of 76,000 records was a daunting task. Thus, we applied a machine learning-supported literature screening approach. We started by manually screening a subset of records, i.e., 1,000, to select relevant documents by reading their titles, abstracts, and keywords. Then, we used this subset to train support vector machine classifiers using *sklearn* (Chang and

Lin, 2011; Pedregosa et al., 2011) to prioritize documents likely to be relevant from the remaining records [see O'Mara-Eves et al. (2015) for a full discussion of machine-learning assisted screening approaches]. As new documents were screened, we re-trained the machine learning models to re-prioritize the remaining documents. We used stopping criteria for determining when it was deemed unlikely that more than 5% of relevant documents had yet to be identified (Callaghan and Müller-Hansen, 2020) (see Figure S1). Then, we collected the relevant documents' full text, mainly PDF, for further screening. Our collection resulted in the full text of 1,651 out of 1,843 relevant records due to restricted access to some documents. Those articles were behind a paywall not accessible from the authors' institutes or other means, e.g., www.researchgate.net. We again screened these full texts to make sure that they were related to food and urban agriculture and were in English. This screening returned 1,455 relevant documents.

2.2. Topic modeling

We used the full text of the relevant documents to identify the topics covered by existing literature on urban agriculture. For this, our study applied topic modeling, an unsupervised machine learning technique, instead of predefining the topics manually. Topic modeling is a statistical model that helps discover abstract "topics" from a set of documents (Blei, 2012). It provides a probability distribution of the topics for each document, also known as theta (θ), and a probability distribution of words for each topic, also called beta (β) or phi (ϕ). In other words, topic modeling clusters word and phrase patterns within the documents to a predefined number of topics to best characterize them. Identifying the optimum number of topics is crucial. If the number of topics is too small, the topics could be too general. If it is too large, the topics could be too many with some overlap or hardly interpretable. Thus, we chose 14 topics because of the jumps in Figure S2, following the method suggested by Nikita (2016). We used the R Package "topicmodels" for topic modeling (Grün and Hornik, 2011).

A few topics could be grouped into one larger theme, given the similarities in word probabilities with each other. For example, topics “Alternative livelihood” and “Alternative food supply” could be combined into one theme. For grouping the topics, we conducted hierarchical clustering of the probability distribution of words for each topic, i.e., beta (β). Based on this clustering, we grouped these topics into 11 themes considering the Hellinger distance of 0.4 (see Figure S3).

We named these topics by analyzing the top probable words in each topic, i.e., words with a large value for β or ϕ. Our interpretation of a topic was based on the documents for which it was a primary topic, i.e., the most probable topic or a large value for θ. Further, we conducted a bibliometric analysis to understand these topics' temporal and spatial dynamics. This analysis was based on the publication year of the document and study area, mainly country, disregarding the authors' affiliations. Most studies focused on urban agriculture in one country, while a few covered multiple countries. Since one document could comprise many topics, we also investigated correlations among these topics and their networks. This investigation helped us to understand co-occurrence among topics.

3. Results

3.1. Urban agriculture topics

We identified 14 topics related to urban agriculture by systematically analyzing the current literature (Figure 2). Some of this literature was primarily associated with one topic, while others were broad, covering more than one. A few words were also the most probable word in many topics. We observed this overlap because these words, e.g., *urban*, *garden*, and *agriculture*, were common terminology across urban agriculture literature and were included in our search criterion. Nevertheless, their occurrence probabilities varied across the topic (Figure S4). Each topic focused on a unique and distinct domain. For example, Topic1 (small-scale ground-based) showed the word *garden* as the dominant one, in contrast to other topics.

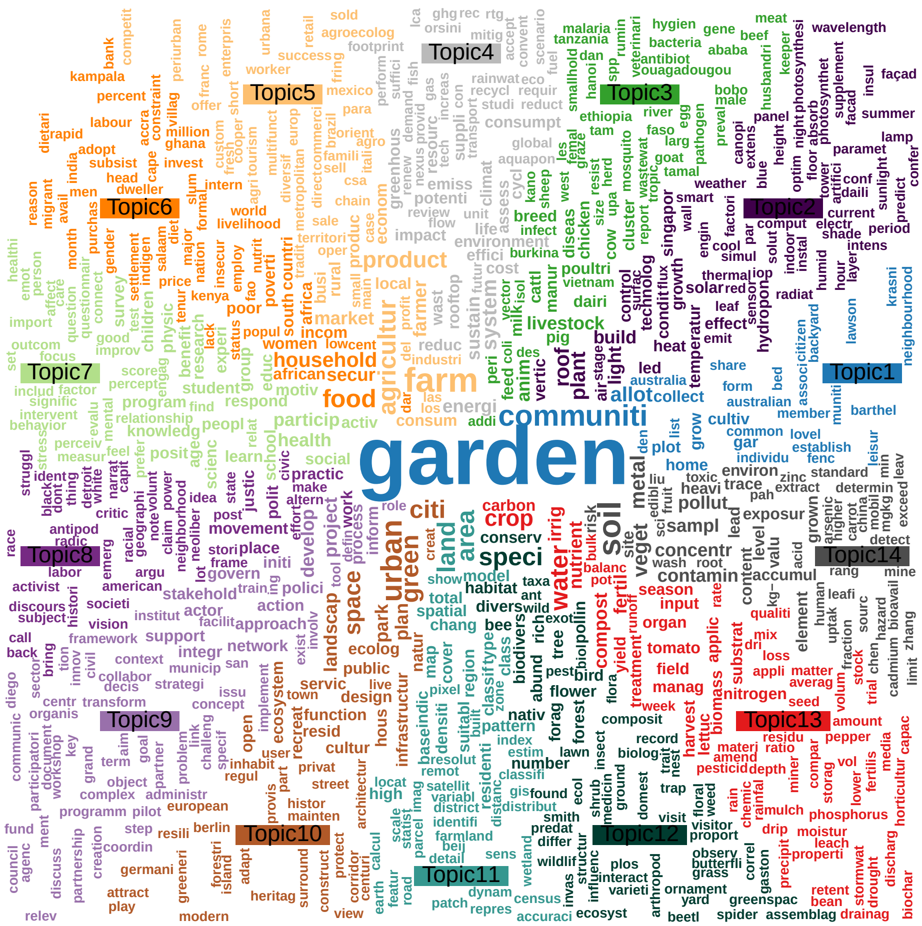

Figure 2: Word cloud of the 14 topics, grouped into 11 themes. It shows the probability distribution of words for each topic. A larger font size means a higher word occurrence probability. The 11 themes are Small-scale ground-based (Topic1), Building-integrated systems (Topic2), Urban livestock (Topic3), Food systems transformation potential (Topic4), Food supply and livelihoods (Topic5, Topic6), Health and educational benefits (Topic7), Social space and urban development (Topic8, Topic9), Green infrastructure and urban planning (Topic10), Urban land cover and ecosystem services (Topic11, Topic12), Water and other agricultural inputs (Topic13), and Health and other risks (Topic14).

We grouped the 14 topics into 11 themes based on hierarchical clustering (see Figure S3). Three themes are related to the types of urban agriculture, i.e., small-scale ground-based, building-integrated systems, and urban livestock. Six themes highlight the multi-functionality of urban agriculture. Their coverage ranges from a broad topic, e.g., food supply and livelihoods, to a specific one, e.g., ecosystem services and biodiversity. The last two themes are related to the underlying challenges associated with urban agriculture, including required inputs. The sections below briefly describe the topics with these themes.

3.1.1. Small-scale ground-based systems

Various forms of ground-based urban agriculture exist worldwide on a small scale. They include allotment, community, and home gardens. Among the 1,455 documents, the 52 documents primarily address these small-scale ground-based systems, highlighting their multi-functionalities (see Topic1 in Figure 2). For example, Breuste and Artmann (2015) underscore the important role of allotment gardens in Salzburg (Austria) in providing recreation and nature experience. However, their importance in food production is declining there. In contrast, a case study in Hobart (Australia) shows that affordable access to vegetables motivates one to grow vegetables in home gardens, mainly for low-income households (Kirkpatrick and Davison, 2018). Inhabitants can have different motivations for engaging in urban agriculture. A case study from Hangzhou (China) highlights that inhabitants support converting public open spaces to community gardens because of food quality, entertainment, and saving expenses (He and Zhu, 2018).

3.1.2. Building-integrated systems

Urban agriculture could also be integrated into buildings. These building-integrated systems are becoming popular in recent decades across the world. It is the primary topic of the 109 relevant documents (see Topic2 in Figure 2). The two main types of building-integrated systems are rooftop and vertical farming. Different forms of rooftop farming include soil-based, soil-less, conditioned, and unconditioned systems. Vertical farming comprises hydroponics, aquaponics, aeroponic, and other soil-based multi-layer agriculture.

Many studies highlight the social, economic, and environmental benefits of building-integrated systems and their designs. Mainly, they could enhance food safety and security for urban populations (Despommier, 2011). For example, case studies in Vancouver (Canada) show that green roofs and walls could provide 54% of the vegetable demand and contribute to greenhouse gas emissions reduction (Roehr and Laurenz, 2008a). In the meantime, they could also decrease buildings' heating and cooling energy demand and reduce the urban heat island effect (Roehr and Laurenz, 2008b). A Singaporean case study highlights the adequate availability of sunlight for farming on under-utilized vertical spaces of residential buildings (Song et al., 2018). However, in the case of limited sunlight and indoors, vertical farming can be carried out using Light Emitting Diodes with photo-synthetically active radiation (Uddin and Suliaman, 2021; Chaudhry and Mishra, 2019; Kozai et al., 2016). Monitoring technologies are also available to ensure optimum plant growth in such building-integrated conditioned systems. For example, Pramono et al. (2020) design monitoring systems for hydroponic. However, McCartney and Lefsrud (2018) highlight that sustainability of available technologies and energy efficiency are important issues to be considered in these building-integrated conditioned systems. The environmental benefits of these systems could be offset if applied technologies are unsustainable and energy intensive.

3.1.3. Urban livestock

Besides crop cultivation, livestock rearing is also a part of urban agriculture in many low-income countries (Abdulkadir et al., 2012). The 67 relevant documents have urban livestock as their primary topic (see Topic3 in Figure 2). For example, Roessler et al. (2016) present that urban farmers in Ouagadougou (Burkina Faso) and Tamale (Ghana) keep a wide range of livestock (e.g., pigs, cattle, goats, and poultry) together with crop cultivation. Similarly, poultry is the dominant livestock in Kampala (Uganda), followed by pigs, cattle, goats, and sheep (Komakech et al., 2014). Several studies highlight various aspects of urban livestock, including their sustainability aspects (Hellyward et al., 2019).

For example, it is an additional source of household income in many countries (Gillah et al., 2012), e.g., Ethiopia (Ayenew et al., 2011) and Tanzania (Swai et al., 2005). However, improper management of urban livestock also poses environmental and health risks, including disease transmission. For example, a Morogoro (Tanzania) case study highlights the risk of contamination with potential zoonotic pathogens due to improper manure management practices (Lupindu et al., 2012). Another disease risk practice is consuming dead and sick animals (Alarcon et al., 2017). Besides livestock management, using wastewater to irrigate urban agriculture could also contaminate its produce, e.g., bacterial contamination (Fuhrimann et al., 2016) and antimicrobial resistance (Bougnom et al., 2019). Due to these linkages with health risks, our unsupervised topic model also bundles wastewater-related studies with urban livestock. These risks could be reduced with proper management, e.g., sanitation facilities (Martinez et al., 2013), recycling manure for crop production (Diogo et al., 2013), and awareness raising (Alarcon et al., 2017).

3.1.4. Food systems transformation potential

Promoting urban agriculture can contribute to sustainable food systems transformation. The 64 relevant documents, including 13 review articles, mention this potential as the primary topic (see Topic4 in Figure 2). For example, Specht et al. (2014) and Thomaier et al. (2015) describe the contributions of building-integrated systems in providing economic outputs (e.g., food, non-food, and non-market goods), environmental benefits (e.g., recycled resources and reduced food miles), and social advantages (e.g., food security, education, and connecting consumers to food production). Orsini et al. (2014) estimate that 77% of the vegetable requirements of Bologna (Italy) could be met by rooftop farming together with biodiversity enrichment. Interestingly, a multidimensional sustainability study shows that urban agriculture in Makassar (Indonesia) is more sustainable in the economic dimension than the ecological one (Abdullah et al., 2017). Accordingly to Sanyé-Mengual et al. (2018), better crop management and garden design could reduce the environmental impacts of urban agriculture. These examples highlight the need for proper management and design for urban agriculture to contribute to sustainable food systems transformation (Goldstein et al., 2016b). Moreover, a wider uptake of urban agriculture requires community behaviour change and appropriate policy measures (Ghosh et al., 2008). A survey of urban dwellers in Berlin (Germany) reveals that urban agriculture businesses are socially acceptable only if combined with ecological and social goals (Specht et al., 2016). However, business opportunities in urban agriculture, e.g., rooftop farming, are still untapped because most of the current rooftop farms focus on social-educational goals and improving urban living quality (Appolloni et al., 2021). Overcoming barriers to urban agriculture is crucial for up-scaling its food systems transformation potential, which may vary across regions.

3.1.5. Food supply and livelihoods

Many studies elaborate on urban agriculture's contribution to enhancing food supply and livelihoods, highlighting more specific aspects. Our literature analysis results in two topics about these aspects.

Food production in urban and peri-urban areas is considered an innovative approach to supplying food, non-food, and non-market goods. It is the primary topic of the 93 relevant documents (see Topic5 in Figure 2). Urban agriculture is a new opportunity for high-yield vegetable production because of its higher yield than traditional farming in general (Payen et al., 2022). Case studies from Beijing (China) and Milan (Italy) present agro-tourism enterprises as an innovative form of urban agriculture, which integrate urban-rural development, besides supplying food (Yang et al., 2010; Spagnoli and Mundula, 2021). Similarly, Guzmán Fernández et al. (2020) highlight other non-marketable benefits of urban agriculture in Mexico City (Mexico), which include creating jobs, reconnecting with nature, and knowledge transfer. Diekmann et al. (2020) also presents similar benefits from urban agriculture in San Francisco (United States). However, these alternative approaches to supply food need to be connected with the mainstream system (e.g., supermarkets) and traditional local and small-scale producers for upscaling their benefits and transforming broken food systems (James, 2016).

Urban agriculture also provides households and farmers with an alternative form of livelihood. These aspects of urban agriculture are the primary topic of the 135 relevant documents (see Topic6 in Figure 2). For example, a review study highlights that urban households will continue strongly engaging in agricultural activities in low-income countries (De Bon et al., 2010). Engagement in urban agriculture could also increase urban households' income, improve their living standard, and provide other livelihood benefits (Van Averbeke, 2007) together with increased food access (Khumalo and Sibanda, 2019). Urban agriculture needs to be promoted and supported to obtain these benefits. A Malawian case study highlights that these supports would be more effective if targeted to poor women by providing agricultural extension services and wealthier farmers to increase the employment opportunities associated with urban agriculture (Mkwambisi et al., 2011). Moreover, issues related to residential development, land tenure, transport infrastructure, and the use of urban spaces need to be adequately addressed to ensure households' ability to produce, sell, and access food (Davies et al., 2021b).

3.1.6. Social and public health benefits

The social and public health benefits of urban agriculture are the primary topic of the 113 relevant documents (see Topic7 in Figure 2). Social benefits of urban agriculture include education and learning (Rahm, 2002; Hong et al., 2021), community network and social capital (Audate et al., 2021; Kirby et al., 2021), reconnecting with agricultural practices and nature (Cattivelli, 2020; Artmann et al., 2021), and knowledge exchange (Dobson et al., 2020; Sanyé-Mengual et al., 2020). Urban inhabitants are motivated to participate in urban agriculture to eat safe and healthy food and obtain these social benefits (Bellows et al., 2009). Besides providing healthy diets, urban agriculture contributes to a healthy and active lifestyle (Van den Berg et al., 2010; Fisher-Maltese et al., 2018; Stubberfield et al., 2022), healing, therapy, and recovery of patients, (Jeong et al., 2020; Heckman, 2012), and improvements in mental health (Koay and Dillon, 2020; Harada et al., 2021).

3.1.7. Social space and urban development

Many studies have highlighted that urban agriculture is a means for urban transformations. Our literature analysis results in two topics related to this theme.

Urban agriculture provides social space for grassroots sustainability movements (Turner, 2011; Hawkes and Acott, 2013; Atkinson and Viloria, 2013), which is the primary topic of the 181 relevant documents (see Topic8 in Figure 2). Guerrilla gardening is an example of such movement, which has been practised to express the need to transform urban spaces (Adams and Hardman, 2014; Mikadze, 2015). Similarly, school gardens connect children to food production and consumption, education, nature, and stewardship (Cairns, 2017), leading to more sustainable futures (Moore et al., 2015). A case study of Dublin (Ireland) and Belfast (Northern Ireland) highlights that allotment gardens could reduce social barriers, foster knowledge exchanges, and generate empathy among their practitioners (Corcoran and Kettle, 2015). However, there might be conflicts among urban gardeners with different visions. Nevertheless, such conflicts may also positively result in cultural disruption and destabilized hierarchies (Aptekar, 2015). Studies also highlight that urban agriculture could enhance food justice and reduce inequalities, mainly for disadvantaged populations (Milbourne, 2012; Miller, 2015; Aptekar and Myers, 2020; Sbicca and Myers, 2017).

Sustainable urban development by promoting urban agriculture (Jahrl et al., 2021) is the primary topic of the 115 relevant documents (see Topic9 in Figure 2). For example, Roth et al. (2015) highlight that urban agriculture can stimulate and support urban renewal and regeneration of the German Ruhr Area. Similarly, a case study in Central Jakarta (Indonesia) highlights urban agriculture's contribution to sustainable urban development based on productive green space, social cohesion, and food expenditure saving (Jap et al., 2021). A successful governance strategy to promote urban agriculture requires emphasizing various social, economic, and environmental benefits associated with urban agriculture, addressing city-specific needs beyond food production (Prové et al., 2016). Here, governments could play essential roles by facilitating multi-stakeholder processes, developing appropriate policies, conversing existing urban farms, and allocating land for urban agriculture (Halloran and Magid, 2013). In return, local government partnerships with urban agricultural movements could foster community development (Gough and Accordino, 2013). Since urban development is also linked with urban policies, our unsupervised topic model bundles documents related to urban food policies with this topic (Moschitz, 2018; Vara-Sánchez et al., 2021)

3.1.8. Green infrastructure and Urban planning

Urban agriculture is a part of green infrastructure and nature-based solutions that promotes the greening of cities (Contesse et al., 2018). It is the primary topic of the 131 relevant documents, considering cultural and historical aspects and modern urban planning (see Topic10 in Figure 2). For example, the historical Persian Gardens in Iranian cities consist of ornamental and agricultural plants (Farzin et al., 2020; Khalilnezhad, 2016). Similarly, Chiayi City (Taiwan) has green alleys with edible plants as a part of the cultural landscape (Lee et al., 2017). These examples show the existence of urban agriculture for a long time in the form of green spaces (Casadei and Bazzocchi, 2017; Liu, 2011). Currently, urban agriculture is also becoming popular in modern urban planning for incorporating green spaces in cities (Bohn and Chu, 2021), reviving their economies (Nefs et al., 2013), and reusing abandoned infrastructure (Matacz and Świątek, 2021). For example, Middle et al. (2014) argue integrating community gardens into public parks is an innovative approach to providing ecosystem services in cities. A case study of Flint, Michigan (United States), highlights an urban agricultural approach to deal with vacated land in shrinking cities to make them more sustainable and livable (Pallagst et al., 2017). Similarly, Szopińska-Mularz and Lehmann (2019) depict that obsolete inner-city car-parking infrastructures in cities in the United Kingdom could be used for urban agriculture, e.g., hydroponics.

3.1.9. Urban land cover and ecosystem services

Many studies have highlighted urban agriculture as a land cover and landscape component. It links rural and urban areas, provides various ecosystem services, and shelters biodiversity. Our literature analysis results in two topics related to these aspects of urban agriculture.

The first topic is mainly related to urban agriculture as a land cover and landscape component, appearing primarily in the 99 relevant documents (see Topic11 in Figure 2). These documents include studies applying remote sensing and GIS techniques to spatially map urban agriculture, its characteristics, and its changes across time (Ghosh and Head, 2009; Pulighe and Lupia, 2016; Smith et al., 2017; Haase et al., 2019). Here, we mainly highlight urban-rural linkages instead of discussing the methods. Peri-urban agriculture, i.e., farming around cities, is a land cover and landscape component that links urban and rural areas with multiple socioeconomic and environmental functions (Serra et al., 2018). For example, wastewater from urban areas could be used to irrigate peri-urban farms (Jampani et al., 2020). However, rapid urbanization also puts pressure on peri-urban agriculture, converting it into built-up areas and transforming barren land for agricultural use (Jampani et al., 2020). Nevertheless, market-oriented farmers could also adapt to rapid urbanization and utilize the provided opportunities by commercialization, specialization, and intensification of their farming under certain conditions (Follmann et al., 2021).

The second topic is ecosystem services and biodiversity related to urban agriculture. It is the primary topic of the 103 relevant documents, including seven reviews (see Topic12 in Figure 2). Besides supplying food, urban agriculture provides various ecosystem services, including pollination, pest control, climate resilience, water regulation, nutrient cycling, recreation, and other cultural services (Lin et al., 2015; Cabral et al., 2017; Speak et al., 2015). However, there might be trade-offs among these ecosystem services depending on urban agriculture management (Taylor et al., 2017). For example, Stenchly et al. (2019)

highlight a potential trade-off between bio-control of pests and pollination services. Areas of urban agriculture are also considered biodiversity hotspots, including flora diversity (Borysiak et al., 2017; Tew et al., 2021). A case study of two cities in Canada shows a high level of functional trait diversity of wild bees in community gardens (Normandin et al., 2017). Similarly, another study highlights allotment gardens as an alternative to natural habitats for bumble bees (Ahrné et al., 2009). Urban agriculture, mainly soil-based, is also rich in invertebrate species (Smith et al., 2006), e.g., ground beetles, ants, spiders, millipedes, gastropods, and rove beetles (Braschler et al., 2020). Moreover, urban agriculture with ponds and trees could also harbor amphibians, birds, and mammals (Loram et al., 2011).

3.1.10. Water and other agricultural inputs

Urban agriculture requires water and other agricultural inputs and provides water-related ecosystem services, a primary topic of 83 documents. Several studies investigate the water and nutrient balance of urban agriculture. For example, Wang et al. (2008) and Abdulkadir et al. (2013) highlight nutrient surplus in urban and peri-urban vegetable farms in Nanjing and Wuxi (China) and Kano (Nigeria), respectively. Excess application of fertilizers is a problem in many urban agriculture systems, which leads to nutrient pollution and poses a risk to water bodies and soil quality (Wielemaker et al., 2019; Abdalla et al., 2012; Kong et al., 2015; Small et al., 2019). Addressing this risk requires an optimum application of fertilizer to maintain crop yields and minimize nutrient loss. Doing so with the application of compost in urban agriculture could help close the urban nutrient loop Shrestha et al. (2020). Regarding irrigation, various types of water are used in urban agriculture depending on locations, e.g., greywater (Rodda et al., 2011), wastewater (Kurian et al., 2013), harvested rainwater (Clark et al., 2019), and advanced irrigation systems (Rodríguez-Delfín, 2011). Moreover, urban agriculture also reduces stormwater and rainwater runoffs (Aloisio et al., 2016; Whittinghill et al., 2015; Kolasa-Więcek and Suszanowicz, 2021), which in return also lowers irrigation water demand (Harada et al., 2018).

3.1.11. Health and other risks

Consumption of urban agricultural produce might also pose health risks which depend on various factors associated with urban farming practices (Menefee and Hettiarachchi, 2017). The 110 relevant documents highlight these risks as their primary topic (see Topic14 in Figure 2). Broadly, these factors are soil and water contamination and air pollution. Urban soils could be contaminated with toxic heavy metals and polycyclic aromatic hydrocarbons, mainly associated with farming in previous industrial sites (Thomas and Lavkulich, 2015), proximity to industry, mining zones, and roads (Kabala et al., 2009; Liu et al., 2019; Wang et al., 2011, 2021), and substrate used for farming (Meck et al., 2020; Papafotiou et al., 2016). Similarly, air pollution and rainwater irrigation could lead to heavy metal contamination in vegetables produced in urban areas (Li et al., 2012). The uptake of these contaminants by plants, their bioavailability, and health risks depend on various factors, e.g., their concentrations, type of contaminant, type of plant species, and species variety (Romanova and Lovell, 2021). Moreover, various measures are available to reduce health risks from such contamination, including the washing of vegetables before human consumption (Schreck et al., 2012), treating wastewater before irrigation (García-Gómez et al., 2002), and using soil amendments and raised-beds in case of contaminated soils (Defoe et al., 2014). Therefore, promoting and up-scaling urban agriculture must tackle these risks to obtain social, economic, and environmental benefits.

3.2. Topic evolution

In recent decades, publications on urban agriculture have increased with variations in the topics they covered (Figure 3). In the 1970s, there were only a few publications on urban agriculture, which increased to 900 in the 2010s. More interestingly, we have already identified over 400 publications in the 2020s.

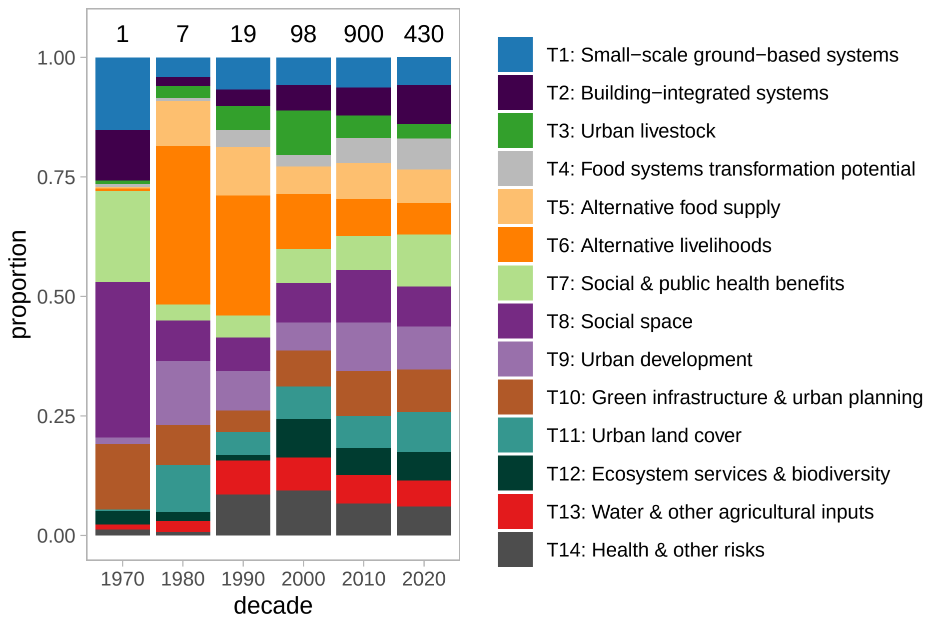

Figure 3: Distribution probability of the 14 topics (T1–T14) on urban agriculture literature across the six decades. Bar heights represent the average distribution proportions. The number on the top of the bars provides the publication count for the decade.

Regarding topics, the focus on urban agriculture research has also evolved during the last decades (Figure 3). Among the 14 topics, urban agriculture as an alternative livelihood was the most dominant topic in the literature until the 2000s. Afterward, Topic5 (Alternative livelihoods) has diminished. In the 2000s, other dominant topics were urban livestock and health and other risks associated with urban agriculture. Currently, urban livestock is the least prevalent topic. However, health and other risks related to urban agriculture are still a non-negligible topic. Recently, there has been an increase in the proportion of the topic of building-integrated systems, mirroring the gaining popularity of these systems worldwide. Other prominent topics in recent decades are social and public health benefits, social space, and urban development. Still, water and other inputs for agriculture are a non-negligible topic.

3.3. Topic spatial distribution

Urban agriculture research is conducted worldwide, mostly with case studies at the city level, covering 96 countries (Figure 4). Some studies also investigate urban agriculture in more than one country or without geographical focus (Figure 5). A majority of urban agriculture research is from high-income countries, namely the United States, the United Kingdom, Italy, Australia, and Spain. It shows a massive investment in research and the importance of urban agriculture in these countries. Considerable urban agriculture research is also conducted in many middle-income countries. For example, we observe at least 20 publications on urban agriculture from China, Indonesia, South Africa, India, Ghana, and Brazil. However, there are less than 15 publications from 76 countries worldwide. Nevertheless, it highlights the global scientific interest in urban agriculture research.

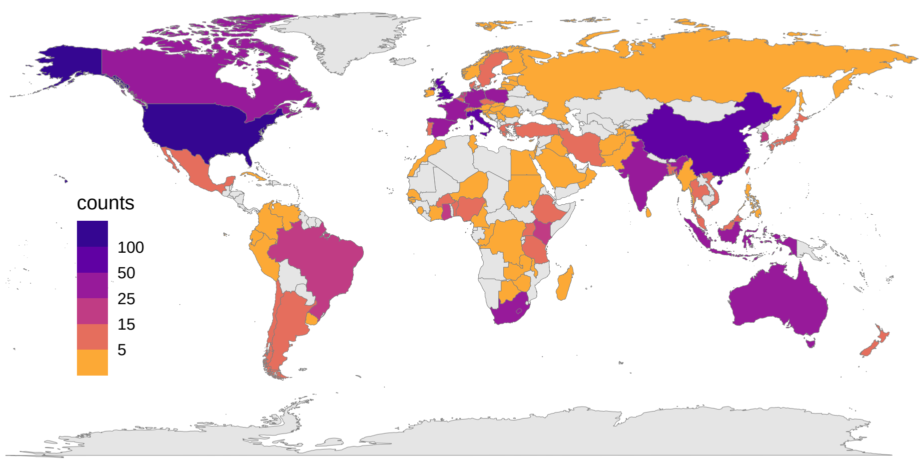

Figure 4: Spatial distribution of urban agriculture research based on publication counts at a country scale, represented by color codes. The grey color represents countries and regions where we did not identify published research on urban agriculture. The map shows only studies that focused on a single country. It excludes studies without a geographical focus, e.g., reviews.

The most dominant topic of urban agriculture research varies worldwide (Figure 5). For example, the potential of urban agriculture to transform food systems is the most dominant topic in Ghana. However, this topic is not so prominent in studies from Spain, Indonesia, Italy, and Singapore. The health and other risks associated with urban agriculture is the most dominant topic in Germany and Netherlands. For Singapore, one of the most prevalent topics is urban agriculture as a green infrastructure and an urban planning component. A few topics are widely analyzed in many countries. Studies from developed and developing countries show a common interest in these topics. Specifically, provisioning social space from urban agriculture is the most dominant topic in a few countries, mainly Spain, South Africa, Brazil, and Poland. Many countries, such as South Korea, India, Canada, and Kenya, have social and public health benefits from urban agriculture as a dominant topic. Surprisingly, alternative food supply and livelihood topics are not so prominent in many countries.

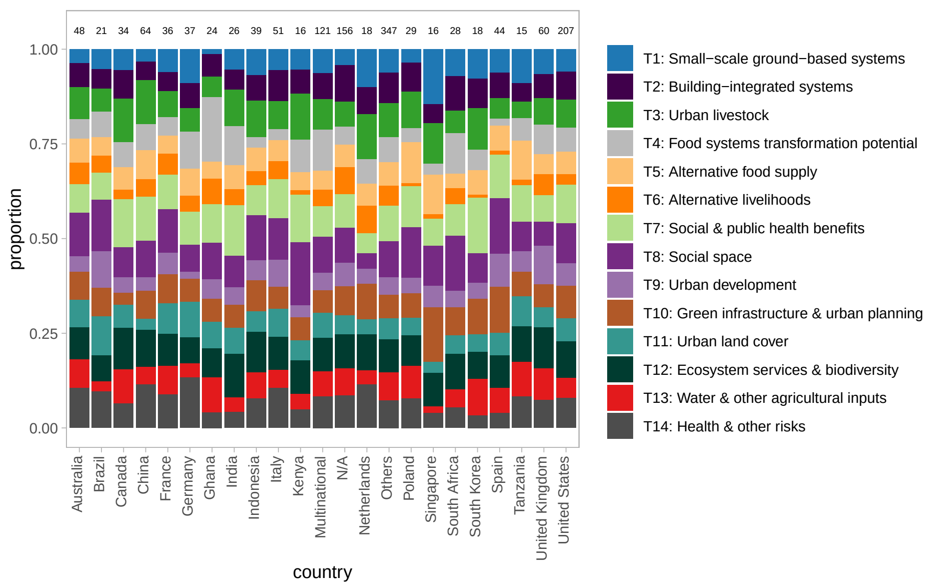

Figure 5: Distribution probability of the 14 topics (T1–T14) on urban agriculture literature worldwide at a country scale. Bar heights represent average distribution proportions. The number on the top of the bars provides the publication count. We group the countries with less than 15 publications into “Others”. “Multinational” represents studies that focused on more than one country. “N/A” are the studies without a geographical focus.

3.4. Topic co-occurrence and network

The 14 topics on urban agriculture are likely to co-occur in the same document, reflecting close linkages among the topics (Figure 6). For example, Topic1 (Small-scale ground-based systems) is more likely to occur together with Topic12 (Ecosystem services & biodiversity), Topic13 (Water & other agricultural inputs), or Topic14 (Health & other risks). We observed these co-occurrences because many studies highlight either ecosystem services and biodiversity in the allotment and community gardens or input requirements and soil contamination aspects of these gardens. Similarly, Topic3 (Urban livestock) is likely to co-occur with many other topics, e.g., Topic4 (Food systems transformation potential), Topic5 (Alternative food supply), Topic6 (Alternative livelihoods), Topic12 (Ecosystem services & biodiversity), and Topic14 (Health & other risks). These co-occurrences reflect the importance of urban livestock together with their challenges. Within a topic, the probability of top words is mostly positively correlated, with a few exceptions of anti-correlations. For example, there is an anti-correlation between the probability of the words *allot* and *communiti* belonging to Topic1. It is mainly because many studies on this topic either focus on allotment or community gardens.

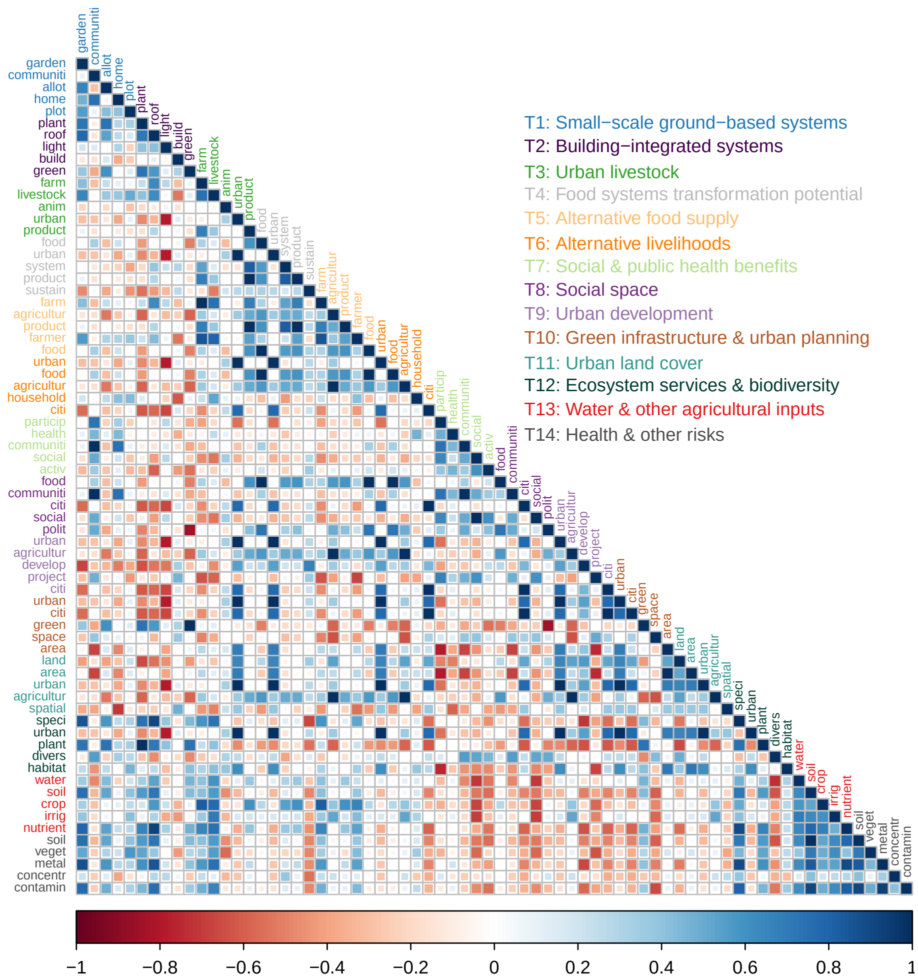

Figure 6: Heat map showing spearman correlation coefficient between occurrence from the 14 topics (T1–T14). The positive correlations reflect the co-occurrence of the words. The reddish colour represents a positive correlation, and the bluish colour shows a negative correlation. The areas of coloured squares are proportional to the absolute value of the correlation coefficient.

Some of the top words from the 14 topics are more connected or isolated than others (Figure 7). The most connected words with positive correlations in terms of occurrence probability in a topic are *urban*, *nutrient*, *roof*, *garden*, *livestock*, and *metal* (Figure 7, left). Since *urban* appears as the top most probable word in seven of 14 topics, it is unsurprising to see *urban* as one of the most prominent words. However, the other five words appear at the top most probable word for only one topic. Nevertheless, these words are connected positively with several words in other topics. The most isolated words with a lot of negative correlations in terms of occurrence probability in a topic are *light*, *project*, *develop*, *plant*, *area*, and *space* (Figure 7, right). Using artificial light for indoor farms is an emerging topic in urban agriculture literature. Thus, we identify *light* as the most isolated words. A reason behind the other five most isolated words is also either their use in a specific context, e.g., *project* and *develop*, or their synonyms being more prominent, e.g., *garden* instead of *area* and *space*.

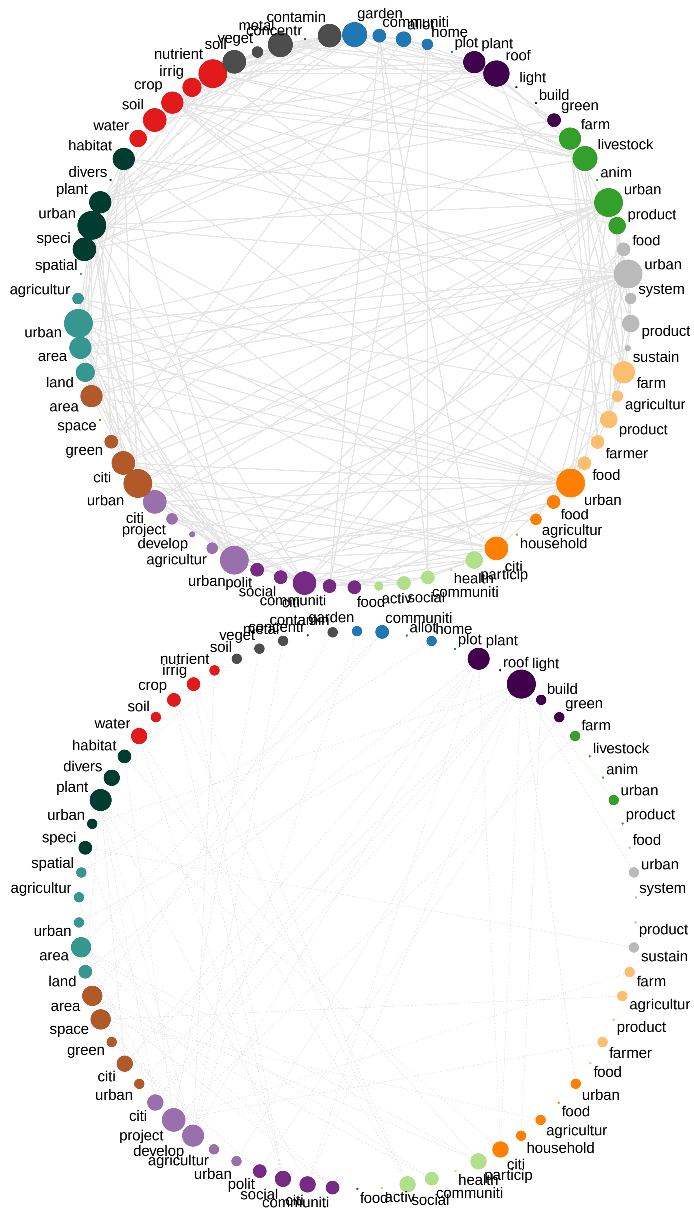

Figure 7: The networks of the top five words from the 14 topics with positive (top) and negative (bottom) correlations in terms of occurrence probability in a topic. The larger bubbles in the network based on positive correlations are the most connected words among the topics (top). In contrast, the most isolated words among the topics are reflected by the larger bubbles in the network based on negative correlations (bottom). The bubble size represents the connections based on positive or negative correlations presented in Figure 6. We plot the networks considering the absolute correlation coefficient greater than 0.6 to avoid over-interpretation of correlation analysis.

4. Discussion

Our systematic literature review identified multiple aspects of urban agriculture, grouped into 14 topics. These topics highlight urban agriculture's social, economic, and environmental benefits and associated risks. We documented increased publications on urban agriculture in recent years. This increase shows that urban agriculture is becoming a part of scientific discourse on various topics based on its multi-functionality. Our review brings several novelties and insights compared to the existing studies on urban agriculture.

First, we provide a holistic review of urban agriculture literature compared to its limited aspects highlighted by most studies. Our broad keyword search strategy enables us to cover an extensive body of literature on urban agriculture, i.e., around 76,000 records for initial screening. It is essential to provide robust evidence of urban agriculture benefits and limitations, which are increasingly debated. As a contribution to this debate, we found a high agreement among the literature on the multi-functionality of urban agriculture. These functionalities include food, livelihoods, income, biodiversity, education, and health. However, several publications also highlight the constraints of urban agriculture. For example, urban agriculture can supply city inhabitants with fruits and vegetables, an essential part of healthy diets. Still, it cannot provide their total calorie and nutrient demands (De Simone et al., 2023). Urban agriculture is a multi-functional infrastructure in or around cities, which offers several socioeconomic and environmental benefits but requires various inputs and might pose health risks.

Second, our study systematically covers various topics the existing urban agriculture literature raises. For this, we apply topic modeling to identify topics based on machine learning instead of manual selection to minimize manual biases in choosing the topics. For example, we identify urban livestock as a separate topic. This topic is not widely covered by the existing reviews (Palma et al., 2015). Moreover, our study uses the full text of the relevant document for topic modeling instead of using only their abstracts. Our 14 topics represent a wide range of discussions on urban agriculture, including its forms, multi-functionalities, and potential risks. Notably, we could identify ground-based and building-integrated systems as separate topics in the literature. These different urban agriculture forms have their own strength and limitations. For example, building-integrated indoor systems, e.g., vertical farming, require artificial light and other agricultural inputs. This form of urban agriculture could provide food on a commercial scale. However, its benefits would be undermined without an efficient system. In contrast, small-scale ground-based systems could provide other social, economic, and environmental benefits and produce food on a less commercial or non-commercial scale. Still, urban agriculture could pose health risks and demand intensive agricultural inputs depending on its management and surrounding environment. Therefore, raising awareness of sustainable practices is essential while promoting and up-scaling urban agriculture to obtain its multi-functional benefits. The sustainability aspects should be further explored with more in situ observations, such as resource-saving and climate mitigation effects.

Third, we bring attention to the spatio-temporal distribution of 14 urban agriculture topics. We found that certain topics are more co-occurring in the same literature than others. Studies from developed and developing countries didn't show differences in prioritizing specific topics. A few topics (e.g., Social space and Social & public health benefits) are common interests for all. Building-integrated systems are becoming increasingly popular worldwide (Van Delden et al., 2021). It might be due to the technological readiness of various forms of building-integrated systems for a broader implementation (Herrero et al., 2020). Regarding urban agriculture benefits, social, environmental, and urban development aspects are becoming more prominent in recent decades. This shift indicates that the function of urban health, a feature of the urban society as a whole, now dominates the interest in urban agriculture for particular social groups. An increased proportion of the topic on the food system transformational potential of urban agriculture also hints in the same direction. It may also indicate a decrease in the interest in urban agriculture as an expression of alternative livelihoods but the mainstreaming of green ideology. It might be becoming less critical what urban agriculture does with those who practice it. More important would be how this form of agriculture transforms the city. This finding highlights the increasing multi-functional role of urban agriculture in providing other social benefits besides food. Thus, we argue that promoting urban agriculture requires accounting for its social, economic, and environmental benefits besides food provisioning.

We acknowledge several limitations to our study. First, our review does not include grey literature on urban agriculture because of limiting our search to only two databases. Since our aim is a systematic analysis, it is a challenge to cover grey literature systematically, including its quality control. Our review was also restricted by our keyword search strategy, selection of English publications, and full-text availability. We could have used various synonyms of urban agriculture during the keyword search. Despite these limitations, we were able to cover a substantial amount of literature, including studies from different countries worldwide. We assumed that information provided in the non-English language is also somewhat reported in those publications. Nevertheless, literature assessment based on English articles generally has a problem. It misses non-English publications, including much grey literature, as highlighted by the recent study on national biodiversity assessments (Amano et al., 2023). Additionally, we tried our best to collect the full text of the articles. Mainly, it was challenging to obtain the full text of some recent articles due to paywalls. However, we could include much of the older literature in our analysis because we did not find full text for only nine publications before 2000. This hurdle highlights the need for open science for sound evidence synthesis.

Second, our method also has some limitations. The topic modeling approach requires a pre-defined number of static topics. We tackle these limitations by identifying an optimum topic number and analyzing topic evolution across the study period. Further, we applied a qualitative method for our study based on vast literature instead of qualitative approaches based on stakeholders. Nevertheless, our review also included qualitative studies covering stakeholders' perspectives. Nevertheless, combining quantitative, qualitative, and knowledge co-creation approaches would be a way forward for a holistic understanding (Pradhan, 2023).

Third, the topic modeling approach does not model sentence structure and provides the distribution of topics over documents and the distribution of words over topics. Therefore, it may miss nuances in the meaning of the text. Fourth, a topical analysis does not account for semantics and conclusions, i.e., concrete positions or findings within one topic. We attempt to overcome these limitations by interpreting each topic by having a closer look at the literature for which it is the primary topic. Overall, these limitations are common in large-scale literature reviews, and we acknowledged these limitations in a comprehensive and rigorous analysis of the literature.

With the application of a systematic approach, we believe that our study provides a robust foundation for promoting urban agriculture considering its multi-functionalities and limitations. For example, as the 2030 Agenda for Sustainable Development envisioned, urban agriculture could contribute to ending hunger, mainly by providing fresh fruits and vegetables. In the meantime, it could synergise with other Sustainable Development Goals (SDGs), e.g., no poverty (SDG 2) and life on land (SDG 15). However, a more detailed study is required to understand the interlinkages between SDGs and urban agriculture. The adequate improvement in urban agriculture to alleviate the trade-offs among SDG targets remain unknown as well. Nevertheless, our review highlights that urban agriculture could help urban transformation towards sustainable cities and communities (SDG 11). Thus, we would argue that sustainable urban planning and development needs to consider urban agriculture as an essential component, which is also a part of green spaces and infrastructures. Moreover, our findings are also crucial contributions to the upcoming report on urban and peri-urban food systems by the High-Level Panel of Experts on Food Security and Nutrition. The report is planned for 2024. We synthesise robust evidence, discussed and highlighted above, based on an extensive body of literature, which could be used in this upcoming report.

5. Conclusion

We conducted a semi-automated systematic review of the existing literature on urban agriculture based on the topic modeling approach. Our review highlights that urban agriculture is multi-functional, providing more than food. In recent years, the literature increasingly emphasizes urban agriculture's social, economic, and environmental benefits. These benefits include urban agriculture as a component of the city's green spaces and infrastructures. Urban agriculture can potentially produce a share of food demands, mainly vegetables. However, there might also be health risks from consuming food from urban agriculture grown in polluted and contaminated soil, water, and air. Additionally, the environmental benefits of urban agriculture could be offset when it is practised unsustainably based on inefficient use of agricultural inputs and energy. Urban agriculture may not always be associated with lower carbon, energy, or water costs. Only judicious management strategies identified from a whole life-cycle assessment of the existing and planned projects could ensure these benefits of urban agriculture. It may be impractical for all forms of urban agriculture to perform better than traditional agriculture in all environmental domains. Trade-offs may occur. For example, improving management for irrigation would be a priority in arid cities to maintain residential water requirements instead of promoting water-intensive ground-based urban agriculture systems. Therefore, promoting urban agriculture should encourage efficient and sustainable practices and incentivise urban agriculture for its multi-functionality besides food provisioning.

Acknowledgement

P. Pradhan thanks the Food System Economics Commission, funded by the IKEA Foundation, grant agreement no. G-2009-01682 for financially supporting this research and acknowledges funding by German Academic Exchange Service (DAAD) for ForHimSDG project (Projekt-ID 57611837) with financial support from the Federal Ministry for Economic Cooperation and Development of Germany (BMZ). The opinions, findings, and conclusions or recommendations expressed in this material are those of the author/authors and do not necessarily reflect the view of the IKEA Foundation. Many thanks go to Jan Minx for providing exposure to various techniques for evidence synthesis, Lilian Kupfer and Marion De Simone for supporting the screening of the literature, and Diego Rybski for the comments and suggestions.

References

Abdalla, S.B., Predotova, M., Gebauer, J., Buerkert, A., 2012. Horizontal nutrient flows and balances in irrigated urban gardens of khartoum, sudan. Nutrient Cycling in Agroecosystems 92, 119–132.

Abdulkadir, A., Dossa, L., Lompo, D.P., Abdu, N., Van Keulen, H., 2012. Characterization of urban and peri-urban agroecosystems in three west african cities. International journal of agricultural sustainability 10, 289–314.

Abdulkadir, A., Leffelaar, P.A., Agbenin, J.O., Giller, K.E., 2013. Nutrient flows and balances in urban and peri-urban agroecosystems of kano, nigeria. Nutrient cycling in agroecosystems 95, 231–254.

Abdullah, A., Dirawan, G.D., Pertiwi, N., 2017. Sustainability of ecology and economic of urban farming development: case study in makassar city, south sulawesi province. Ecology, Environment and Conservation 23, 125–130.

Adams, D., Hardman, M., 2014. Observing guerrillas in the wild: Reinterpreting practices of urban guerrilla gardening. Urban Studies 51, 1103–1119.

Ahrné, K., Bengtsson, J., Elmqvist, T., 2009. Bumble bees (bombus spp) along a gradient of increasing urbanization. PloS one 4, e5574.

Al-Kodmany, K., 2018. The vertical farm: A review of developments and implications for the vertical city. Buildings 8, 24.

Alarcon, P., Fèvre, E.M., Muinde, P., Murungi, M.K., Kiambi, S., Akoko, J., Rushton, J., 2017. Urban livestock keeping in the city of nairobi: diversity of production systems, supply chains, and their disease management and risks. Frontiers in Veterinary Science 4, 171.

Aloisio, J., Tuininga, A., Lewis, J.D., 2016. Crop species selection effects on stormwater runoff and edible biomass in an agricultural green roof microcosm. Ecological Engineering 88, 20–27.

Amano, T., Berdejo-Espinola, V., Akasaka, M., de Andrade Junior, M.A., Blaise, N., Checco, J., Çilingir, F.G., Citegetse, G., Corella Tor, M., Drobniak, S.M., et al., 2023. The role of non-english-language science in informing national biodiversity assessments. Nature Sustainability , 1–10.

Appolloni, E., Orsini, F., Specht, K., Thomaier, S., Sanye-Mengual, E., Pennisi, G., Gianquinto, G., 2021. The global rise of urban rooftop agriculture: A review of worldwide cases. Journal of Cleaner Production 296, 126556.

Aptekar, S., 2015. Visions of public space: Reproducing and resisting social hierarchies in a community garden, in: Sociological Forum, Wiley Online Library. pp. 209–227.

Aptekar, S., Myers, J.S., 2020. The tale of two community gardens: green aesthetics versus food justice in the big apple. Agriculture and Human Values 37, 779–792.

Artmann, M., Sartison, K., Ives, C.D., 2021. Urban gardening as a means for fostering embodied urban human–food connection? a case study on urban vegetable gardens in germany. Sustainability Science 16, 967–981.

Atkinson, A., Viloria, J., 2013. Readjusting to reality 2: Transition? City 17, 580–605.

Audate, P.P., Cloutier, G., Lebel, A., 2021. The motivations of urban agriculture practitioners in deprived neighborhoods: A comparative study of montreal and quito. Urban Forestry & Urban Greening 62, 127171.

Ayenew, Y.A., Wurzinger, M., Tegegne, A., Zollitsch, W., 2011. Socioeconomic characteristics of urban and peri-urban dairy production systems in the north western ethiopian highlands. Tropical animal health and production 43, 1145–1152.

Bellows, A., Alcaraz, G., Vivar, T., 2009. Gardening as tool to foster health and cultural identity in the context of international migration: Attitudes and constraints in a female population, in: II International Conference on Landscape and Urban Horticulture 881, pp. 785–792.

Beniston, J., Lal, R., 2012. Improving soil quality for urban agriculture in the north central us, in: Carbon sequestration in urban ecosystems. Springer, pp. 279–313.

Van den Berg, A.E., van Winsum-Westra, M., De Vries, S., Van Dillen, S.M., 2010. Allotment gardening and health: a comparative survey among allotment gardeners and their neighbors without an allotment. Environmental Health 9, 1–12.

Blei, D.M., 2012. Probabilistic topic models. Communications of the ACM 55, 77–84.

Bohn, K., Chu, D., 2021. Food-productive green infrastructure: Enabling agroecological transitions from an urban design perspective. Urban Agriculture & Regional Food Systems 6, e20017.

Borysiak, J., Mizgajski, A., Speak, A., 2017. Floral biodiversity of allotment gardens and its contribution to urban green infrastructure. Urban Ecosystems 20, 323–335.

Bougnom, B.P., Zongo, C., McNally, A., Ricci, V., Etoa, F.X., Thiele-Bruhn, S., Piddock, L.J., 2019. Wastewater used for urban agriculture in west africa as a reservoir for antibacterial resistance dissemination. Environmental research 168, 14–24.

Braschler, B., Gilgado, J.D., Zwahlen, V., Rusterholz, H.P., Buchholz, S., Baur, B., 2020. Ground-dwelling invertebrate diversity in domestic gardens along a rural-urban gradient: Landscape characteristics are more important than garden characteristics. PloS one 15, e0240061.

Breuste, J.H., Artmann, M., 2015. Allotment gardens contribute to urban ecosystem service: case study salzburg, austria. Journal of Urban Planning and Development 141, A5014005.

Cabral, I., Keim, J., Engelmann, R., Kraemer, R., Siebert, J., Bonn, A., 2017. Ecosystem services of allotment and community gardens: A leipzig, germany case study. Urban Forestry & Urban Greening 23, 44–53.

Cairns, K., 2017. Connecting to food: cultivating children in the school garden. Children's Geographies 15, 304–318.

Callaghan, M.W., Müller-Hansen, F., 2020. Statistical stopping criteria for automated screening in systematic reviews. Systematic Reviews 9, 1–14.

Casadei, F., Bazzocchi, G., 2017. Urban agriculture and city development in bologna (italy): notes in historical perspective, in: International Symposium on Greener Cities for More Efficient Ecosystem Services in a Climate Changing World 1215, pp. 357–362.

Cattivelli, V., 2020. The motivation of urban gardens in mountain areas. the case of south tyrol. Sustainability 12, 4304.

Chang, C.C., Lin, C.J., 2011. LIBSVM: A library for support vector machines. ACM Transactions on Intelligent Systems and Technology 2, 27:1–27:27. URL: https://doi.org/10.1145/1961189.1961199, doi:10.1145/1961189.1961199.

Chaudhry, A.R., Mishra, V.P., 2019. A comparative analysis of vertical agriculture systems in residential apartments, in: 2019 Advances in Science and Engineering Technology International Conferences (ASET), IEEE. pp. 1–5.

Clark, G.G., Jamal, R., Weidhaas, J., 2019. Roofing material and irrigation frequency influence microbial risk from consuming homegrown lettuce irrigated with harvested rainwater. Science of the Total Environment 651, 1011–1019.

Clinton, N., Stuhlmacher, M., Miles, A., Uludere Aragon, N., Wagner, M., Georgescu, M., Herwig, C., Gong, P., 2018a. A global geospatial ecosystem services estimate of urban agriculture. Earth's Future 6, 40–60.

Clinton, N., Stuhlmacher, M., Miles, A., Uludere Aragon, N., Wagner, M., Georgescu, M., Herwig, C., Gong, P., 2018b. A global geospatial ecosystem services estimate of urban agriculture. Earth's Future 6, 40–60. doi:10.1002/2017EF000536.

Contesse, M., Van Vliet, B.J., Lenhart, J., 2018. Is urban agriculture urban green space? a comparison of policy arrangements for urban green space and urban agriculture in santiago de chile. Land use policy 71, 566–577.

Corcoran, M.P., Kettle, P.C., 2015. Urban agriculture, civil interfaces and moving beyond difference: the experiences of plot holders in dublin and belfast. Local Environment 20, 1215–1230.

Costello, C., Oveysi, Z., Dundar, B., McGarvey, R., 2021. Assessment of the effect of urban agriculture on achieving a localized food system centered on Chicago, IL using robust optimization. Environmental Science & Technology 55, 2684–2694. doi:10.1021/acs.est.0c04118.

Davies, J., Hannah, C., Guido, Z., Zimmer, A., McCann, L., Battersby, J., Evans, T., 2021a. Barriers to urban agriculture in Sub-Saharan africa. Food Policy 103, 101999.

Davies, J., Hannah, C., Guido, Z., Zimmer, A., McCann, L., Battersby, J., Evans, T., 2021b. Barriers to urban agriculture in sub-saharan africa. Food Policy 103, 101999.

De Bon, H., Parrot, L., Moustier, P., 2010. Sustainable urban agriculture in developing countries. a review. Agronomy for sustainable development 30, 21–32.

De Simone, M., Pradhan, P., Kropp, J.P., Rybski, D., 2023. A large share of berlin's vegetable consumption can be produced within the city. Sustainable Cities and Society Accepted.

Defoe, P.P., Hettiarachchi, G.M., Benedict, C., Martin, S., 2014. Safety of gardening on lead-and arsenic-contaminated urban brownfields. Journal of Environmental Quality 43, 2064–2078.

Despommier, D., 2011. The vertical farm: controlled environment agriculture carried out in tall buildings would create greater food safety and security for large urban populations. Journal für Verbraucherschutz und Lebensmittelsicherheit 6, 233–236.

Diekmann, L.O., Gray, L.C., Thai, C.L., 2020. More than food: The social benefits of localized urban food systems. Frontiers in Sustainable Food Systems 4, 534219.

Diogo, R.V., Schlecht, E., Buerkert, A., Rufino, M.C., van Wijk, M.T., 2013. Increasing nutrient use efficiency through improved feeding and manure management in urban and peri-urban livestock units of a west african city: a scenario analysis. Agricultural systems 114, 64–72.

Dobson, M.C., Reynolds, C., Warren, P.H., Edmondson, J.L., 2020. "my little piece of the planet": the multiplicity of well-being benefits from allotment gardening. British Food Journal .

Dong, J., Gruda, N., Li, X., Cai, Z., Zhang, L., Duan, Z., 2022. Global vegetable supply towards sustainable food production and a healthy diet. Journal of Cleaner Production 369, 133212.

Farzin, S., Khalilnezhad, S.M.R., Moradzadeh Mirzaei, S., Zarei, A., 2020. Investigation on recognition of the type of multifunctional landscape in persian garden (case study: Akbariyeh world heritage garden). MANZAR, the Scientific Journal of landscape 12, 6–17.

Fisher-Maltese, C., Fisher, D.R., Ray, R., 2018. Can learning in informal settings mitigate disadvantage and promote urban sustainability? school gardens in washington, dc. International Review of Education 64, 295–312.

Follmann, A., Willkomm, M., Nduru, G., Owuor, G., Dannenberg, P., 2021. Continuity under change: Towards a spatiotemporal understanding of market-oriented urban and peri-urban agriculture–insights from kenya. Applied Geography 135, 102528.

Fuhrimann, S., Pham-Duc, P., Cissé, G., Tram, N.T., Ha, H.T., Ngoc, P., Nguyen-Viet, H., Vuong, T.A., Utzinger, J., Schindler, C., et al., 2016. Microbial contamination along the main open wastewater and storm water channel of hanoi, vietnam, and potential health risks for urban farmers. Science of the Total Environment 566, 1014–1022.

García-Gómez, R., Chávez-Espinosa, J., Mejía-Chávez, A., Durán-de Bazúa, C., 2002. Microbiological determinations of some vegetables from the xochimilco zone in mexico city, mexico. Revista Latinoamericana de Microbiología 44, 24–30.

Ghosh, S., Head, L., 2009. Retrofitting the suburban garden: morphologies and some elements of sustainability potential of two australian residential suburbs compared. Australian Geographer 40, 319–346.

Ghosh, S., Vale, R., Vale, B., 2008. Local food production in home gardens: measuring on-site sustainability potential of residential development. International Journal of Environment and Sustainable Development 7, 430–451.

Gillah, K., Kifaro, G., Madsen, J., et al., 2012. Urban and peri urban dairy farming in east africa: A review on production levels, constraints and opportunities. Livestock Research for Rural Development 24, 198.

Goldstein, B., Hauschild, M., Fernández, J., Birkved, M., 2016a. Testing the environmental performance of urban agriculture as a food supply in northern climates. Journal of Cleaner Production 135, 984–994.

Goldstein, B., Hauschild, M., Fernández, J., Birkved, M., 2016b. Urban versus conventional agriculture, taxonomy of resource profiles: a review. Agronomy for Sustainable Development 36, 1–19.

Gough, M.Z., Accordino, J., 2013. Public gardens as sustainable community development partners: Motivations, perceived benefits, and challenges. Urban Affairs Review 49, 851–887.

Graefe, S., Buerkert, A., Schlecht, E., 2019. Trends and gaps in scholarly literature on urban and peri-urban agriculture. Nutrient Cycling in Agroecosystems 115, 143–158.

Grün, B., Hornik, K., 2011. topicmodels: An r package for fitting topic models. Journal of statistical software 40, 1–30.

Guzmán Fernández, K., Moreno-Calles, A.I., Casas, A., Blancas, J., 2020. Contributions of urban collective gardens to local sustainability in mexico city. Sustainability 12, 7562.

Haase, D., Jänicke, C., Wellmann, T., 2019. Front and back yard green analysis with subpixel vegetation fractions from earth observation data in a city. Landscape and urban planning 182, 44–54.

Halloran, A., Magid, J., 2013. The role of local government in promoting sustainable urban agriculture in dar es salaam and copenhagen. Geografisk Tidsskrift-Danish Journal of Geography 113, 121–132.

Harada, K., Hino, K., Iida, A., Yamazaki, T., Usui, H., Asami, Y., Yokohari, M., 2021. How does urban farming benefit participants' health? a case study of allotments and experience farms in tokyo. International journal of environmental research and public health 18, 542.

Harada, Y., Whitlow, T.H., Todd Walter, M., Bassuk, N.L., Russell-Anelli, J., Schindelbeck, R.R., 2018. Hydrology of the brooklyn grange, an urban rooftop farm. Urban Ecosystems 21, 673–689.

Harris, J., de Steenhuijsen Piters, B., McMullin, S., Bajwa, B., de Jager, I., Brouwer, I.D., 2023. Fruits and vegetables for healthy diets: Priorities for food system research and action. Science and Innovations for Food Systems Transformation , 87–104.

Hawkes, F.M., Acott, T.G., 2013. People, environment and place: The function and significance of human hybrid relationships at an allotment in south east england. Local environment 18, 1117–1133.

He, B., Zhu, J., 2018. Constructing community gardens? residents' attitude and behaviour towards edible landscapes in emerging urban communities of china. Urban Forestry & Urban Greening 34, 154–165.

Heckman, J.R., 2012. Human contact with plants and soils for health and well-being, in: Soils and human health. CRC Press, pp. 227–240.

Hellyward, J., Rachmat, A., et al., 2019. The sustainability index of dairy cattle area in padang panjang city, in: IOP Conference Series: Earth and Environmental Science, IOP Publishing. p. 012038.

Herrero, M., Thornton, P.K., Mason-D'Croz, D., Palmer, J., Benton, T.G., Bodirsky, B.L., Bogard, J.R., Hall, A., Lee, B., Nyborg, K., et al., 2020. Innovation can accelerate the transition towards a sustainable food system. Nature Food 1, 266–272.

Hong, I.K., Yun, H.K., Jung, Y.B., Lee, S.M., Lee, C.s., 2021. Resetting the evaluation indicators for school garden education service. Journal of People, Plants, and Environment 24, 245–256.

Hume, I., Summers, D., Cavagnaro, T., 2021. Self-sufficiency through urban agriculture: Nice idea or plausible reality? Sustainable Cities and Society 68, 102770. doi:https://doi.org/10.1016/j.scs.2021.102770.

Jahrl, I., Moschitz, H., Cavin, J.S., 2021. The role of food gardening in addressing urban sustainability–a new framework for analysing policy approaches. Land Use Policy 108, 105564.

James, S.W., 2016. Beyond 'local'food: how supermarkets and consumer choice affect the economic viability of small-scale family farms in sydney, a ustralia. Area 48, 103–110.

Jampani, M., Amerasinghe, P., Liedl, R., Locher-Krause, K., Hülsmann, S., 2020. Multi-functionality and land use dynamics in a peri-urban environment influenced by wastewater irrigation. Sustainable Cities and Society 62, 102305.

Jap, J.J., Soesilo, T.E., Tumuyu, S.S., 2021. Assessing urban agriculture's development in central jakarta, in: IOP Conference Series: Earth and Environmental Science, IOP Publishing. p. 012125.

Jeong, S.J., Yoo, E.H., Kim, J.S., Jang, H.S., Lee, G.W., 2020. Analysis of 2010s research trends in research on agro-healing in south korea. Journal of People, Plants, and Environment 23, 267–276.

Kabala, C., Chodak, T., Szerszen, L., Karczewska, A., Szopka, K., Fratczak, U., et al., 2009. Factors influencing the concentration of heavy metals in soils of allotment gardens in the city of wroclaw, poland. Fresenius Environmental Bulletin 18, 1118–1124.

Khalilnezhad, S., 2016. Principles of integration of the agriculture and pleasure greeneries in persian gardens, in: VI International Conference on Landscape and Urban Horticulture 1189, pp. 39–42.

Khumalo, N.Z., Sibanda, M., 2019. Does urban and peri-urban agriculture contribute to household food security? an assessment of the food security status of households in tongaat, ethekwini municipality. Sustainability 11, 1082.

Kirby, C.K., Specht, K., Fox-Kämper, R., Hawes, J.K., Cohen, N., Caputo, S., Ilieva, R.T., Lelièvre, A., Poniży, L., Schoen, V., et al., 2021. Differences in motivations and social impacts across urban agriculture types: Case studies in europe and the us. Landscape and Urban Planning 212, 104110.

Kirkpatrick, J.B., Davison, A., 2018. Home-grown: Gardens, practices and motivations in urban domestic vegetable production. Landscape and Urban Planning 170, 24–33.

Koay, W.I., Dillon, D., 2020. Community gardening: Stress, well-being, and resilience potentials. International Journal of Environmental Research and Public Health 17, 6740.

Kolasa-Więcek, A., Suszanowicz, D., 2021. The green roofs for reduction in the load on rainwater drainage in highly urbanised areas. Environmental Science and Pollution Research 28, 34269–34277.

Komakech, A.J., Banadda, N.E., Gebresenbet, G., Vinnerås, B., 2014. Maps of animal urban agriculture in kampala city. Agronomy for sustainable development 34, 493–500.

Kong, A.Y., Rosenzweig, C., Arky, J., 2015. Nitrogen dynamics associated with organic and inorganic inputs to substrate commonly used on rooftop farms. HortScience 50, 806–813.

Kozai, T., Fujiwara, K., Runkle, E.S. (Eds.), 2016. LED lighting for urban agriculture. Springer.

Kriewald, S., Pradhan, P., Costa, L., Ros, A.G.C., Kropp, J.P., 2019. Hungry cities: how local food self-sufficiency relates to climate change, diets, and urbanisation. Environmental Research Letters 14, 094007.

Kurian, M., Ratna Reddy, V., Dietz, T., Brdjanovic, D., 2013. Wastewater re-use for peri-urban agriculture: a viable option for adaptive water management? Sustainability science 8, 47–59.

Lee, T.I., Hsieh, Y., Huang, J.H., Huang, L., Li, J., Syu, M., Wu, P., et al., 2017. Spatial factors affecting patterns of edible landscaping in urban lanes and alleys. WIT Transactions on Ecology and the Environment 214, 131–139.

Li, D., Bou-Zeid, E., Oppenheimer, M., 2014. The effectiveness of cool and green roofs as urban heat island mitigation strategies. Environmental Research Letters 9, 055002.

Li, F.L., Liu, C.Q., Yang, Y.G., Bi, X.Y., Liu, T.Z., Zhao, Z.Q., 2012. Natural and anthropogenic lead in soils and vegetables around guiyang city, southwest china: a pb isotopic approach. Science of the Total Environment 431, 339–347.

Li, M., Jia, N., Lenzen, M., Malik, A., Wei, L., Jin, Y., Raubenheimer, D., 2022. Global food-miles account for nearly 20% of total food-systems emissions. Nature Food , 1–9.

Lin, B.B., Philpott, S.M., Jha, S., 2015. The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. Basic and applied ecology 16, 189–201.

Liu, H.L., 2011. Study on regional cultural landscape classification of kunming's leisure agricultural garden, in: Applied Mechanics and Materials, Trans Tech Publ. pp. 546–549.

Liu, Z., Lu, Y., Song, X., Jones, K., Sweetman, A.J., Johnson, A.C., Zhang, M., Lu, X., Su, C., 2019. Multiple crop bioaccumulation and human exposure of perfluoroalkyl substances around a mega fluorochemical industrial park, china: Implication for planting optimization and food safety. Environment international 127, 671–684.

Loram, A., Warren, P., Thompson, K., Gaston, K., 2011. Urban domestic gardens: the effects of human interventions on garden composition. Environmental Management 48, 808–824.

Lupindu, A., Ngowi, H., Dalsgaard, A., Olsen, J., Msoffe, P., 2012. Current manure management practices and hygiene aspects of urban and peri-urban livestock farming in tanzania .

Martellozzo, F., Landry, J., Plouffe, D., Seufert, V., Rowhani, P., Ramankutty, N., 2014. Urban agriculture: a global analysis of the space constraint to meet urban vegetable demand. Environmental Research Letters 9, 064025. doi:10.1088/1748-9326/9/6/064025.

Martinez, L., Collazo, G., Cabrera, L., Bernabe-Ortiz, A., Ramos-Peña, Y., Oberhelman, R., 2013. Free-ranging chickens in households in a periurban shantytown in peru—attitudes and practices 10 years after a community-based intervention project. The American Journal of Tropical Medicine and Hygiene 89, 229.

Matacz, P., Świątek, L., 2021. The unwanted heritage of prefabricated wartime air raid shelters—underground space regeneration feasibility for urban agriculture to enhance neighbourhood community engagement. Sustainability 13, 12238.

Mbow, C., Rosenzweig, C., Barioni, L.G., Benton, T.G., Herrero, M., Krishnapillai, M., Liwenga, E.T., Pradhan, P., Rivera-ferre, M.G., Sapkota, T., Tubiello, F.N., 2019. Food security, in: Shukla, P., Skea, J., Buendia, E.C., Masson-Delmotte, V., Pörtner, H.O., Roberts, D., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Pereira, J.P., Huntley, P.V.E., Kissick, K., Belkacemi, M., Malley, J. (Eds.), Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Cambridge University Press, Cambridge and New York. Chapter 5: Food Security, pp. 437—550.

McCartney, L., Lefsrud, M., 2018. Protected agriculture in extreme environments: a review of controlled environment agriculture in tropical, arid, polar, and urban locations. Applied Engineering in Agriculture 34, 455–473.

Meck, M.L., Mudimbu, D., Davies, T., 2020. Accumulation of potentially harmful elements in edible parts of vegetables grown on two different geological substrates in zimbabwe. Journal of Geochemical Exploration 208, 106392.

Menefee, D.S., Hettiarachchi, G.M., 2017. Contaminants in urban soils: Bioavailability and transfer, in: Urban soils. CRC Press, pp. 175–198.

Middle, I., Dzidic, P., Buckley, A., Bennett, D., Tye, M., Jones, R., 2014. Integrating community gardens into public parks: An innovative approach for providing ecosystem services in urban areas. Urban forestry & urban greening 13, 638–645.

Mikadze, V., 2015. Ephemeral urban landscapes of guerrilla gardeners: a phenomenological approach. Landscape Research 40, 519–529.

Milbourne, P., 2012. Everyday (in) justices and ordinary environmentalisms: community gardening in disadvantaged urban neighbourhoods. Local Environment 17, 943–957.

Miller, W.M., 2015. Uk allotments and urban food initiatives:(limited?) potential for reducing inequalities. Local Environment 20, 1194–1214.

Mirzabaev, A., Olsson, L., Bezner Kerr, R., Pradhan, P., Guadalupe, M., Ferre, R., Lotze-Campen, H., 2021. Climate change and food systems .

Mkwambisi, D.D., Fraser, E.D., Dougill, A.J., 2011. Urban agriculture and poverty reduction: Evaluating how food production in cities contributes to food security, employment and income in malawi. Journal of International Development 23, 181–203.

Moore, S.A., Wilson, J., Kelly-Richards, S., Marston, S.A., 2015. School gardens as sites for forging progressive socioecological futures. Annals of the Association of American Geographers 105, 407–415.

Moschitz, H., 2018. Where is urban food policy in switzerland? a frame analysis. International Planning Studies 23, 180–194.

Nefs, M., Alves, S., Zasada, I., Haase, D., 2013. Shrinking cities as retirement cities? opportunities for shrinking cities as green living environments for older individuals. Environment and Planning A 45, 1455–1473.

Nikita, M., 2016. Select number of topics for LDA model. https://cran.r-project.org/web/packages/ldatuning/vignettes/topics.html. [Online; accessed 10-August-2022].

Nitya, R., Patil, S., Singh, C., Parama, R., Pryor, C., Poonacha, P., Genes, M., 2022. Cultivating sustainable and healthy cities: A systematic literature review of the outcomes of urban and peri-urban agriculture. Sustainable Cities and Society , 104063.

Normandin, É., Vereecken, N.J., Buddle, C.M., Fournier, V., 2017. Taxonomic and functional trait diversity of wild bees in different urban settings. PeerJ 5, e3051.

de Oliveira Alves, D., de Oliveira, L., 2022. Commercial urban agriculture: A review for sustainable development. Sustainable Cities and Society , 104185.

Orsini, F., Gasperi, D., Marchetti, L., Piovene, C., Draghetti, S., Ramazzotti, S., Bazzocchi, G., Gianquinto, G., 2014. Exploring the production capacity of rooftop gardens (rtgs) in urban agriculture: the potential impact on food and nutrition security, biodiversity and other ecosystem services in the city of bologna. Food Security 6, 781–792.

O'Sullivan, C.A., Bonnett, G.D., McIntyre, C.L., Hochman, Z., Wasson, A.P., 2019. Strategies to improve the productivity, product diversity and profitability of urban agriculture. Agric. Syst. 174, 133–144.

O'Mara-Eves, A., Thomas, J., McNaught, J., Miwa, M., Ananiadou, S., 2015. Using text mining for study identification in systematic reviews: a systematic review of current approaches. Systematic reviews 4, 1–22.

O'Sullivan, C.A., McIntyre, C.L., Dry, I.B., Hani, S.M., Hochman, Z., Bonnett, G.D., 2020. Vertical farms bear fruit. Nature biotechnology 38, 160–162.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., et al., 2021.

The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Systematic reviews 10, 1–11.

Pallagst, K., Fleschurz, R., Trapp, F., 2017. Greening the shrinking city—policies and planning approaches in the usa with the example of flint, michigan. Landscape research 42, 716–727.

Palma, I.P., Toral, J.N., Vázquez, M.R.P., Fuentes, N.F., Hernández, F.G., 2015. Historical changes in the process of agricultural development in cuba. Journal of Cleaner Production 96, 77–84.

Papafotiou, M., Koutri, A., Massas, I., 2016. Heavy metal concentration in sage plants cultivated on an urban green roof or roadside location as affected by substrate type and fertilization, in: VI International Conference on Landscape and Urban Horticulture 1189, pp. 439–442.

Payen, F.T., Evans, D.L., Falagán, N., Hardman, C.A., Kourmpetli, S., Liu, L., Marshall, R., Mead, B.R., Davies, J.A., 2022. How much food can we grow in urban areas? food production and crop yields of urban agriculture: A meta-analysis. Earth's future 10, e2022EF002748.

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R., Dubourg, V., Vanderplas, J., Passos, A., Cournapeau, D., Brucher, M., Perrot, M., Duchesnay, E., 2011. Scikit-learn: Machine Learning in Python. Journal of Machine Learning Research 12, 2825–2830. URL: `http://jmlr.org/papers/v12/pedregosa11a.html`.

Poulsen, M.N., McNab, P.R., Clayton, M.L., Neff, R.A., 2015. A systematic review of urban agriculture and food security impacts in low-income countries. Food Policy 55, 131–146.

Pradhan, P., 2022. Food transport emissions matter. Nature Food , 1–2.

Pradhan, P., 2023. A threefold approach to rescue the 2030 agenda from failing. National Science Review .

Pradhan, P., Kriewald, S., Costa, L., Rybski, D., Benton, T.G., Fischer, G., Kropp, J.P., 2020. Urban food systems: How regionalization can contribute to climate change mitigation. Environmental Science & Technology 54, 10551–10560.

Pradhan, P., Kropp, J.P., 2020. Interplay between Diets, Health, and Climate Change. Sustainability 12, 3878. doi:10.3390/su12093878.

Pradhan, P., Lüdeke, M.K., Reusser, D.E., Kropp, J.P., 2014. Food self-sufficiency across scales: how local can we go? Environmental science & technology 48, 9463–9470.

Pramono, S., Nuruddin, A., Ibrahim, M.H., 2020. Design of a hydroponic monitoring system with deep flow technique (dft), in: AIP Conference Proceedings, AIP Publishing LLC. p. 030195.

Provč, C., Dessein, J., De Krom, M., 2016. Taking context into account in urban agriculture governance: Case studies of warsaw (poland) and ghent (belgium). Land Use Policy 56, 16–26.

Pulighe, G., Lupia, F., 2016. Mapping spatial patterns of urban agriculture in rome (italy) using google earth and web-mapping services. Land use policy 59, 49–58.

Rahm, J., 2002. Emergent learning opportunities in an inner-city youth gardening program. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching 39, 164–184.

Rodda, N., Carden, K., Armitage, N., Du Plessis, H., 2011. Development of guidance for sustainable irrigation use of greywater in gardens and small-scale agriculture in south africa. Water SA 37, 727–738.

Rodríguez-Delfín, A., 2011. Advances of hydroponics in latin america, in: II International Symposium on Soilless Culture and Hydroponics 947, pp. 23–32.

Roehr, D., Laurenz, J., 2008a. Green living envelopes for food and energy production in cities. WIT Transactions on Ecology and the Environment 117, 663–671.

Roehr, D., Laurenz, J., 2008b. Living skins: environmental benefits of green envelopes in the city context. WIT Transactions on Ecology and the Environment 113, 149–158.

Roessler, R., Mpouam, S.E., Muchemwa, T., Schlecht, E., 2016. Emerging development pathways of urban livestock production in rapidly growing west africa cities. Sustainability 8, 1199.

Romanova, O., Lovell, S., 2021. Food safety considerations of urban agroforestry systems grown in contaminated environments. Urban Agriculture & Regional Food Systems 6, e20008.

Roth, M., Frixen, M., Tobisch, C., Scholle, T., 2015. Finding spaces for urban food production – matching spatial and stakeholder analysis with urban agriculture approaches in the urban renewal area of dortmund-hörde, germany. Future of Food: Journal on Food, Agriculture and Society 3, 79–88.

Rybski, D., Pradhan, P., Shutters, S.T., Butsic, V., Kropp, J.P., 2021. Characterizing the sectoral development of cities. PLoS One 16, 1–13. doi:10.1371/journal.pone.0254601.

Sanyé-Mengual, E., Gasperi, D., Michelon, N., Orsini, F., Ponchia, G., Gianquinto, G., 2018. Eco-efficiency assessment and food security potential of home gardening: A case study in padua, italy. Sustainability 10, 2124.

Sanyé-Mengual, E., Specht, K., Vávra, J., Artmann, M., Orsini, F., Gianquinto, G., 2020. Ecosystem services of urban agriculture: perceptions of project leaders, stakeholders and the general public. Sustainability 12, 10446.

Sbicca, J., Myers, J.S., 2017. Food justice racial projects: Fighting racial neoliberalism from the bay to the big apple. Environmental Sociology 3, 30–41.

Schreck, E., Bonnard, R., Laplanche, C., Leveque, T., Foucault, Y., Dumat, C., 2012. Deca: a new model for assessing the foliar uptake of atmospheric lead by vegetation, using lactuca sativa as an example. Journal of environmental management 112, 233–239.

Serra, P., Saurí, D., Salvati, L., 2018. Peri-urban agriculture in barcelona: Outlining landscape dynamics vis à vis socio-environmental functions. Landscape Research 43, 613–631.

Shrestha, P., Small, G.E., Kay, A., 2020. Quantifying nutrient recovery efficiency and loss from compost-based urban agriculture. PloS one 15, e0230996.

Small, G., Shrestha, P., Metson, G.S., Polsky, K., Jimenez, I., Kay, A., 2019. Excess phosphorus from compost applications in urban gardens creates potential pollution hotspots. Environmental Research Communications 1, 091007.

Smith, J.P., Li, X., Turner II, B.L., 2017. Lots for greening: Identification of metropolitan vacant land and its potential use for cooling and agriculture in phoenix, az, usa. Applied Geography 85, 139–151.

Smith, R.M., Warren, P.H., Thompson, K., Gaston, K.J., 2006. Urban domestic gardens (vi): environmental correlates of invertebrate species richness. Biodiversity & Conservation 15, 2415–2438.

Song, X.P., Tan, H.T., Tan, P.Y., 2018. Assessment of light adequacy for vertical farming in a tropical city. Urban forestry & urban greening 29, 49–57.

Spagnoli, L., Mundula, L., 2021. Between urban and rural: Is agricultural parks a governance tool for developing tourism in the periurban areas? reflections on two italian cases. Sustainability 13, 8108.

Speak, A., Mizgajski, A., Borysiak, J., 2015. Allotment gardens and parks: Provision of ecosystem services with an emphasis on biodiversity. Urban Forestry & Urban Greening 14, 772–781.

Specht, K., Siebert, R., Hartmann, I., Freisinger, U.B., Sawicka, M., Werner, A., Thomaier, S., Henckel, D., Walk, H., Dierich, A., 2014. Urban agriculture of the future: an overview of sustainability aspects of food production in and on buildings. Agriculture and human values 31, 33–51.

Specht, K., Weith, T., Swoboda, K., Siebert, R., 2016. Socially acceptable urban agriculture businesses. Agronomy for sustainable development 36, 1–14.

Stenchly, K., Waongo, A., Schaeper, W., Nyarko, G., Buerkert, A., 2019. Structural landscape changes in urban and peri-urban agricultural systems of two west african cities and their relations to ecosystem services provided by woody plant communities. Urban Ecosystems 22, 397–408.

Stubberfield, J., Troldborg, M., Ander, L., Crout, N., Young, S.D., Hough, R.L., 2022. Exercise, urban food production, preparation and consumption: Implications, benefits and risks to grow-your-own (gyo) gardeners. Agronomy 12, 181.

Swai, E., Karimuribo, E., Schoonman, L., French, N., Fitzpatrick, J., Kambarage, D., Bryant, M., 2005. Description, socio-economic characteristics, disease managements and mortality dynamics in smallholder's dairy production system in coastal humid region of tanga, tanzania. Livestock Research for Rural Development 17.

Szopińska-Mularz, M., Lehmann, S., 2019. Urban farming in inner-city multi-storey car-parking structures: adaptive reuse potential. Future Cities and Environment 5, 1.

Taylor, J.R., Lovell, S.T., Wortman, S.E., Chan, M., 2017. Ecosystem services and tradeoffs in the home food gardens of african american, chinese-origin and mexican-origin households in chicago, il. Renewable Agriculture and Food Systems 32, 69–86.

Tew, N.E., Memmott, J., Vaughan, I.P., Bird, S., Stone, G.N., Potts, S.G., Baldock, K.C., 2021. Quantifying nectar production by flowering plants in urban and rural landscapes. Journal of Ecology 109, 1747–1757.

Thomaier, S., Specht, K., Henckel, D., Dierich, A., Siebert, R., Freisinger, U.B., Sawicka, M., 2015. Farming in and on urban buildings: Present practice and specific novelties of zero-acreage farming (zfarming). Renewable Agriculture and Food Systems 30, 43–54.

Thomas, E., Lavkulich, L., 2015. Community considerations for quinoa production in the urban environment. Canadian Journal of Plant Science 95, 397–404.

Turner, B., 2011. Embodied connections: sustainability, food systems and community gardens. Local Environment 16, 509–522.

Uddin, M.R., Suliaman, M., 2021. Energy efficient smart indoor fogponics farming system, in: IOP Conference Series: Earth and Environmental Science, IOP Publishing. p. 012012.

Van Averbeke, W., 2007. Urban farming in the informal settlements of atteridgeville, pretoria, south africa. Water Sa 33.

Van Delden, S., SharathKumar, M., Butturini, M., Graamans, L., Heuvelink, E., Kacira, M., Kaiser, E., Klamer, R., Klerkx, L., Kootstra, G., et al., 2021. Current status and future challenges in implementing and upscaling vertical farming systems. Nature Food 2, 944–956.

Vara-Sánchez, I., Gallar-Hernández, D., García-García, L., Alonso, N.M., Moragues-Faus, A., 2021. The co-production of urban food policies: Exploring the emergence of new governance spaces in three spanish cities. Food Policy 103, 102120.

Wang, H.J., Huang, B., Shi, X.Z., Darilek, J.L., Yu, D.S., Sun, W.X., Zhao, Y.C., Chang, Q., Öborn, I., 2008. Major nutrient balances in small-scale vegetable farming systems in peri-urban areas in china. Nutrient Cycling in Agroecosystems 81, 203–218.

Wang, Y.C., Qiao, M., Liu, Y.X., Arp, H., Zhu, Y.G., 2011. Comparison of polycyclic aromatic hydrocarbon uptake pathways and risk assessment of vegetables from waste-water irrigated areas in northern china. Journal of Environmental Monitoring 13, 433–439.

Wang, Z., Bao, J., Wang, T., Moryani, H.T., Kang, W., Zheng, J., Zhan, C., Xiao, W., 2021. Hazardous heavy metals accumulation and health risk assessment of different vegetable species in contaminated soils from a typical mining city, central china. International journal of environmental research and public health 18, 2617.

Warren, E., Hawkesworth, S., Knai, C., 2015. Investigating the association between urban agriculture and food security, dietary diversity, and nutritional status: A systematic literature review. Food Policy 53, 54–66.

Whittinghill, L.J., Rowe, D.B., Andresen, J.A., Cregg, B.M., 2015. Comparison of stormwater runoff from sedum, native prairie, and vegetable producing green roofs. Urban ecosystems 18, 13–29.

Wielemaker, R., Oenema, O., Zeeman, G., Weijma, J., 2019. Fertile cities: Nutrient management practices in urban agriculture. Science of the total environment 668, 1277–1288.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., Vries, W.D., Sibanda, L.M., Afshin, A., Chaudhary, A., Herrero, M., Agustina, R., Branca, F., Lartey, A., Fan, S., Crona, B., Fox, E., Bignet, V., Troell, M., Lindahl, T., Singh, S., Cornell, S.E., Reddy, K.S., Narain, S., Nishtar, S., Murray, C.J.L., 2019. Food in the anthropocene: the EAT–lancet commission on healthy diets from sustainable food systems. The Lancet 393, 447–492. doi:10.1016/S0140-6736(18)31788-4. publisher: Elsevier.

Yang, Z., Cai, J., Sliuzas, R., 2010. Agro-tourism enterprises as a form of multi-functional urban agriculture for peri-urban development in china. Habitat International 34, 374–385.