Environmental Science

http://www.aimspress.com/

Volume 2, Issue 3, 852-867.
DOI: 10.3934/environsci.2015.3.852
Received date 18 April 2015,
Accepted date 13 August 2015,
Published date 28 August 2015

Review

Urban agriculture in the transition to low carbon cities through urban greening

Mary Thornbush *

Department of Geography, Brock University, 500 Glenridge Avenue, St. Catharines, Ontario, L2S 3A1, Canada

* **Correspondence:** Email: mthornbush@brocku.ca; Tel: +1-905-688-5550;
Fax: +1-905-688-6369.

Abstract: Urban agriculture presents an opportunity to extend food production to cities. This could enhance food security, particularly in developing countries, and allow for adaptation to growing urbanization. This review paper examines current trends in urban agriculture from a global perspective as a mitigation-adaptation approach to climate change adaptation in the midst of a growing world population. Employing vegetation as a carbon capture and storage system encapsulates a soft-engineering strategy that can be easily deployed by planners and environmental managers. In this review, urban agriculture is presented as a land-use solution to counteract the effects of urbanization, and as a means to establish a continuum between cities and the countryside. It espouses the usefulness of urban agriculture to enhance food security while sequestering carbon. As part of urban greening (including newer approaches, such as green roofs and gardens as well as more established forms of greening, such as forests and parks), urban agriculture offers traditionally rural services in cities, thereby contributing to food resources as well as working to alleviate pressing social issues like poverty. It also provides a way to reduce stress on farmland, and creates opportunities for employment and community-building. As part of greening, urban agriculture provides a buffer for pollution and improves environmental (and well as human) health and well-being. This review begins by addressing the physical factors of adopting urban agriculture, such as climate change and development, land use and degradation, technology and management, and experimental findings as well as human factors investigated in the published literature. As such, it presents an integrated approach to urban agriculture that is part of a social-ecological perspective.

Keywords: climate change; mitigation-adaptation; gardening; green roofs; land use;
social-ecological resilience; sustainability; urban food production

1. Introduction

Food has taken center stage in urban sustainability. Oxfam [1] communicated that extreme weather associated with climate change has led to increases in food prices, as in the US due to drought. This calls for research that “stress-tests” the global food system in order to identify vulnerabilities, and advocates policy that builds a resilient food system. Yoshino [2] asserted that much attention has been given to national and global food security problems since the 1990s, arguing that these problems should be considered for homogeneous regions that possess similar cultures, history, and recent experience in industrialization/ urbanization. Such a regional scale consideration of Monsoon Asia, for instance, enables for the location of urgent subjects, including the impact of industrialization/ urbanization on rice-producing societies. Petit [3] considered the main domains at risk for Europe, with agriculture and food security among them.

Rydin et al. [4] extended the adoption of urban agriculture temporally to the past thousand years (p. 2097). They, for example, referred to the farming terraces of Machu Picchu in Peru. Urban agriculture, by definition: “the cultivation, processing, and distribution of food within the city,” is conveyed as a critical response to food shortages and serves the economy and health in urban areas. These authors relayed that a 100 m^2 plot can, within 130 days, sustain a family for a year, providing fruit and vegetables (vitamins A, C, and half of B, plus iron). However, the actual definition of urban agriculture is complicated by its primary support of social goals over food provision [5]. It is also influenced by the local context (location) and research objectives, being heavily dependent on case studies [6]. Nevertheless, urban agriculture is gaining popularity in developed countries, such as the USA, Russia, France, the Netherlands, and Denmark. In Bologna, Italy, for instance, rooftop gardens could provide as much as 12,000 t $year^{-1}$ of vegetables, which satisfies some 77% of demand. These gardens also serve as green corridors extending more than 94 km in length [7].

Urban agriculture could reduce unemployment and poverty in cities as well as create stronger communities. Authors have reviewed the recent literature for low- and middle-income countries (e.g., [8]), where urban populations continue to expand and food security is a problem. Global hotspots for food insecurity continue to be south Asia and sub-Saharan Africa [9]. Moreover, it has been advocated that community and school gardens have received more attention in recent work on urban agriculture [10] and that more attention is needed to address home gardens, which have the potential to drive social change. This is perhaps part of a developing neoliberal (cf. [11]) view of urban agriculture as potentially a food justice mechanism [12] that would oppose limited access and dependency on supermarkets, and can lead to limited selection, scarcity, and missing dietary variety, as in Msunduzi, South Africa [13]. Such supermarket-dependent households are worse-off particularly if they are female-headed, experiencing high levels of unemployment and lower than average incomes.

However, recent studies have shown that urban agriculture has limited poverty alleviation capacity in the way that it is currently practiced and regulated in southern African cities [14]. Often, there is a lack of urban policy governing urban agriculture, and local and central government needs to be involved in its legitimization and institutionalization [15]. A community-based research approach (including participatory mechanisms, cf. [16], such as municipal policy planning, cf. [17]; participatory methods allowing local access through free agricultural markets, as in Cuba, [18]) that is engaging to citizens could help to augment bottom-up (local or community-led) initiatives, such as agroecological movements [18]. However, community-based programs still require greater institutional integration as well as contextual backing [19].

This paper presents a critical review of the literature on urban food production (urban agriculture) and its contribution to food security, while sequestering carbon as part of urban greening and a tool for achieving low carbon cities. The central aim is to present the different facets of the research, whilst focusing on the impact of and adaptation to climate change. Urban agriculture is seen as a tenable mitigation-adaptation strategy against anthropogenic climate change that can benefit urban communities in developing as well as developed countries. Previous literature reviews, as recently for urban community gardens by Guitart et al. [20], have examined the English academic literature, and discovered a dominance for studies in culturally diverse low-income areas. They also unraveled an emphasis on American cities, which dominate the literature on this topic. Moreover, most studies are in the area of social science, and natural-science research is at present under-represented in the literature, with existing physical studies focusing on the conservation potential of community gardens in cities. The current critical review makes a contribution to an integrated physical perspective in the literature that draws from a global perspective and integrates the physical component (of the food production system) to the social dimension of food security.

2. Carbon-sequestering capacity

2.1. Climate change and development

Developing countries are mostly at risk to global temperature increases over 2.5 ℃, particularly as they are dealing with population increases, political crisis, poor resource endowments, and environmental degradation [21]. It is expected, for instance, that countries in the tropics and subtropics as well as those in transition will find it most difficult to adapt to climate change due to marginal farming conditions, degradation of natural resources, and inappropriate technologies acting alongside other stresses [22].

A warming climate could have negative ramifications for agricultural production. For instance, it has been estimated that 1 mm day^{-1} increase in rainfall (predicted for much of the Congo Basin by the 2050s) may trigger an increased frequency of heavy rains in the dry season, when farmers use slash-and-burn agriculture in forests to return nutrients to the soil for cropping [23]. A reduced size of farmers' fields that have undergone slash-and-burn has the potential to increase food insecurity for poor rural families. Other authors, such as Tao et al. [24], have simulated the impact of global warming on rice production and water use in China, discovering a reduced rice-growing period (with 100% probability regardless of whether carbon dioxide (CO_2) fertilization effects are accounted for). Simulated findings indicate that the effects of global warming, especially the interaction between precipitation and potential evapotranspiration, will reduce grain yields and livestock in the western and eastern regions of China, which will ultimately threaten its food security [25].

Wheat, which is the third largest crop in the world (after corn and rice), can be severely impacted by an average temperature of ± 2 ℃ during the growing season, causing reductions of up to 50% in grain production in the main wheat-growing regions of Australia, mainly by increased leaf senescence at temperatures over 34 ℃ [26]. For this reason, it is thought that higher temperatures during the grain-filling stage could lead to yield reductions that compromise global food security.

The impact of climate change for American corn has been the intensification of extremely hot conditions in the primary corn-growing region [27]. These authors found that the effects of climate change were moderated through the integration of energy and agriculture markets. Moreover, there may exist a greater mitigation potential (in terms of greenhouse gas emissions) for rice over wheat and maize systems [28].

2.2. Land use and degradation

It is not always climate-induced weather extremes that trigger food scarcity. Swearingen [29], for instance, connected drought and food security with political stability. For instance, an increasing drought hazard this century for Morocco (due to cultivation in marginal areas and reduced fallow, which have been triggered by European colonization, population pressure, scarcity of new cropland, etc.) has led to reduced food security, increased vulnerability to drought, and drought-related rioting twice in the 1980s. A post-1958 period of cooling in the Indo-Gangetic Plains region, Singh and Sontakke [30] attributed to the expansion and intensification of agricultural activities and increased irrigation. Nevertheless, the authors have also attested to the relevance of meteorological factors (e.g. wind, rainfall) alongside other considerations, such as tectonic disturbances and river sedimentology.

Lal [31] advocated that land-use change and soil cultivation need address, with there being much potential for soil carbon sequestration (through the restoration of degraded soils, biomass production, water purification, and reductions in the rate of atmospheric CO_2 enrichment). He has maintained that soil carbon sequestration could increase cereals and food legumes, as well as roots and tubers, production in developing countries [32]. Doumbia et al. [33] provided experimental support for this assertion through the use of *Aménagement en courbes de niveu* technology, roughly analogous to “ridge-tillage.” This technology significantly increased maize yields by 24% and also increased soil carbon (for sequestration) up to 26%. The latter resulted from reduced erosion, greater rainfall capture, and increased subsoil water, and led to the establishment of shrubs and trees (and further rainfall capture as well as reduced runoff). Their experiments have conveyed that such soil and water conservation technology is capable of increasing food production and at the same time increasing soil organic carbon (by sequestering carbon in soils) and harvesting water.

Lal [34] postulated that soil science is a way forward to feed the number of urban-dwellers that is expected to be 5 billion by 2030, making urban agriculture a high priority. Nevertheless, he has also suggested that global carbon pools (a CO_2 lake) be established for the sequestration of atmospheric CO_2 in order to improve soil quality as well as the efficiency of agronomic input and for world food security [35]. Allotment soils in cities have shown higher concentrations of nutrients, including soil organic carbon (SOC: 32% higher), carbon to nitrogen ratios (C:N: 36%), and total nitrogen (TN: 25%), than arable soils [36]. This has indicated that own-growing (as part of small-scale urban food production) does not necessarily degrade urban soils in comparison to conventional agriculture, and allotments offer opportunities to meet growing food demands.

2.3. Technology and management

African countries, such as Ethiopia, need technical capacities for rainfall observation, forecasting, data management, and modeling [37]. For observation, Zhang et al. [38] proposed the use of satellite remote sensing to obtain information, as of high-temperature damage) for rice in China’s Yangtze River. Liu et al. [39] demonstrated from their study of rice productivity at four sites (Wuchang, Xinygan, Zhenjiang, and Janyuan) in China that global warming would have reduced the length of the rice-growing period and reduced grain yield at all study sites had a breeding effort (of new rice varieties) not been used to stabilize growing duration and increased the harvest index and grain yield.

Management approaches and policies are capable of instigating much change, but there needs to be a substantive amount of research into the current response mechanisms (to climate variability and other shocks) for planned adaptation, which needs to be approached from a multisector perspective, as for instance recognizing fisheries [40]. In particular, management practices that have the potential to improve food security (as well as profitability), as with soil carbon management, are more likely to be adopted [41].

2.4. Experimental methods

It has been argued that simulation models are the most advanced crop yield forecasting systems (e.g., [42]); nevertheless, field experiments (as in Gambia) have revealed much about developing knowledge about terrestrial systems. Too many studies are fixated on simulating impacts (e.g., [43,44]) and not enough are actually executing field-based testing in the search for appropriate (in situ) responses at various scales and from a multisectoral perspective.

Some authors postulate that an empirical approach that is supported by large datasets is needed to potentially provide an (independent) assessment of model parameters, such as the CO_2 fertilization effect [45]. These researchers, for instance, assessed individual countries since 1961 based on measurements of atmospheric CO_2 growth rates and crop yields to test for the average effect of a 1-ppm increase of CO_2 on crop yields of rice, wheat, and maize.

Other experiments, as by Yang et al. [46], have been conducted on the impacts of rising CO_2 on rice yield, as with the Free Air CO_2 Enrichment (FACE) experiments performed in open-air field conditions across the world in order to simulate the future high-CO_2 environment through comparisons of, for example, Iwate, Japan (as a cool temperate climate) and Jiangsu, China (as a warm subtropical climate), and considering both biotic (varieties, insects, disease, weeds) and abiotic (nutrient and water availability, temperature, ozone) factors in order to identify adaptation strategies. These authors more recently reviewed the progress of FACE on C4 crops, based on open-air trials of crop performance, of which sorghum and maize are the most important. Growth and yield of these crops increased to some extent under dry, but not wet, conditions [47].

White et al. [48] reviewed 221 peer-reviewed papers that employed crop simulation models to examine the impact of climate change on agricultural systems. They conveyed that 170 of these papers focus on wheat, maize, soybean, and rice; and that 55 papers are American and another 64 papers are European, which were the two dominant regions studied. A minority of 20 papers examined different tillage practices or crop rotations. The authors also relayed that the impacts were often overestimated with regards climatic variability. Their recommendation is for a coordinated (crop, climate, and soil) data resource.

2.5. Existing limitations

There seems to be a fixation on CO_2 in the literature on global warming. Indeed, very few authors have considered other greenhouse gases. For instance, Shindell et al. [49] were among the few to examine tropospheric ozone and black carbon as part of degraded air quality in the context of global warming. Other authors have also examined nitrous oxide emissions, which increase agricultural production at the cost of contributing to global warming and the depletion of stratospheric ozone, as in the North China Plain [50].

Much of the literature (which is predominantly based on model simulations) calls for adaptation strategies, and requests that they be considered now. Fitt et al. [51], for instance, projected that by the 2050s yields of wheat and oilseed rape will be halved in southern England if arable crop disease epidemics are not controlled. Since they estimated 10–15 years for many strategies to be implemented, they called for decisions to be made soon. The authors also suggested that investments be made in long-term data collation, modeling, and experimental work in order to inform the decision-making process by industry and government.

Few studies have reported advantages for cropping in a warmer climate. For instance, warming was found to increase grain yield (by 16.3%) based on field conditions on the Yangtze Delta Plain, China [52]. For this reason, it is anticipated that warming will actually facilitate winter wheat production in East China. In northeast China cropping systems progressively and actively adapt to warming, with the existing rice cropping region extending northward 80 km in 2006 compared with 1970 [53].

Nevertheless, Gerardeaux et al. [54] were critical about the focus on irrigated rice in India and China at the expense of knowing more about what is happening in other parts of the rice-producing world, such as rain-fed rice-cropping systems in Madagascar. These authors have posited that using a no-tillage system does not help to overcome issues imposed by climate change (due to nitrogen, which also constrains crops in hand-ploughed systems). However, they found that temperature and increased CO_2 have positive effects on rice growth and yields, although sustainability may be threatened.

3. Enhancing food security

There are also human factors to consider that have potential to affect the food-production system, such as human impacts on the environment. For instance, the over-abstraction of water from two dams at Lake Victoria in Uganda has the potential to trigger wetland loss, collapse the tilapia fisheries, enhance lake eutrophication, and led to reduced food security for an impoverished population [55]. Indeed, it has been recognized that food security is very complex, with various factors (in addition to environmental factors), such as agriculture, politics, infrastructure, trade, economics, poverty, education, culture, and religion, influencing it [56].

Scientific research is needed to inform policy and affect development agendas about changes in regional hydrology, sea-level rise, and extreme weather events. For instance, a simulation of future (tropical) African climate that takes land degradation into account stipulates that vegetation protection measures are put into effect [57]. Many cities in sub-Saharan Africa, for instance, have not been integrated into policies (for urban development and planning, even within local government) that are supportive of urban agriculture [58]. There is much current focus (both academic- and policy-driven), however, on urban agriculture in the region of sub-Saharan Africa [59].

There needs to be some consideration of social mitigation. This is especially pertinent since the problem of famine is projected to greatly increase in the twenty-first century, impounding half of the world’s population that already suffers from malnourishment [60]. Reduced meat consumption and increased vegetarian and vegan diets could control problems of large-scale land degradation due to overgrazing as well as animal epidemics [61]. Using examples of water shortage in northern China and the country's food security as well as world energy consumption, Xu et al. [62] argued that managing and mobilizing social resources could be an alternative to mitigating environmental human impacts and adapting to them.

Building is another sector that could drive change in cities. Vernay et al. [63], for instance, postulated that food consumption in cities has been only marginally considered within the eco-city concept and bring attention to urban agriculture. In this deliberation, they recognized the long history of urban agriculture and the important role that it still plays in developing and emerging countries.

Nevertheless, the rural-urban connection has been weakened, as in the North, where good production strictly occurs in rural areas. A "systems integration" approach would effectively integrate food, as for instance in the planning of eco-cities, and factor it in relation to energy production and consumption, transportation, water, waste, land use, and more. The authors suggested ways to integrate food in the Hammarby model, including greenhouses, farms, and green roofs. The latter (green roofs) are limited because of the cost of installation and weight imposed on rooftops despite their benefits of stormwater management and energy savings [64].

Urban agriculture provides opportunities to reduce the energy footprint in food production through reduced transport for locally grown crops and through a reduced reliance on greenhouse-grown foodstuffs (cf. [65]). According to these authors, there is also the possibility of growing climate resilient varieties. There is need for a better understanding of food miles and the impact of urban agriculture on the carbon footprint [66]. The growing demand for locally produced food in North America, including organic produce, provides opportunities for reducing the urban carbon footprint as part of zero carbon food production (e.g., Portland, Oregon and Vancouver, BC, Canada [67]). Developed cities in the northern and southern hemisphere, such as Melbourne, Australia [68], are deploying innovative urban food production schemes in order to promote a distributed and resilient food system.

Indeed, cities can be conceived differently. For instance, as "edible landscapes," where urban public spaces can be employed for food production, as in Seattle's urban forests [69]. These authors recognized the potential for gardening and even livestock production in cities at urban forest sites, functioning to provide goods and services for urban sustainability and providing opportunities for stewardship and social interaction with nature. Likewise, Thaman [70] promoted the use of small-scale urban food gardening, as in small-island states of the Pacific Ocean, in order to stimulate sustainable development (overcoming problems of inequality and poverty, unemployment and falling real wages, and malnutrition and associated diseases) as well as food security. (It is noteworthy that food security is affected by economic impacts at various scales, including for instance inflation affecting the cost of imports and affordability.)

Madaleno [71] similarly stressed the importance of small-scale urban food production; she outlined the nutritional (and environmental) benefits of urban production of fruits and vegetables for the urban poor. Foodstuffs, such as fruits (95% of urban agriculture spaces), medicinal plants (67%, with at least 95 species of plants), spices (37%), vegetables (22%), cereals and tubers (5%) in addition to animal husbandry (34%) comprised 1,444 family plots in Belém, Brazil (as in her Table 1, p. 75). Indeed, there is a history of gardening in this Brazilian city, with over 40% of Belém's urban farmers occupying the land and cultivating it for more than 20 years and about 21% between 10 and 20 years. These foods are grown in a variety of urban plots (vacant lots, private, and public gardens), and include tropical fruits (such as açai (*Euterpe oleracea*), guava (*Psidium guajava*), rose-apple

(*Eugenia malaccensis*), papaya (*Carica papaya*), avocado (*Persea americana*), banana (*Musa*), mango (*Mangifera indica*), lime and lemon (*Citrus limonium, aurantifolia,* and *medica*), coconut (*Cocos nucifera*), aerola cherry (*Malpighia punicifolia*), and cashew (*Anacardium occidentale*) as well as pepper (*Piper nigrum*), chicory (*Eryngium foetidum*) and basil (*Ocimum basilicum*)—in her Table 2, p. 75). One-third of households kept livestock (chickens, ducks, rabbits, and pigs). The author did not expect self-sufficiency in urban agriculture (in urban and peri-urban areas) for cereals and tubers, but anticipated it meeting the increasing demand for fruits and vegetables, particularly from farming at the fringe, as in Belém's greenbelt project administered by municipal government. Here, some 70% of plots are farmed by owners.

However, this is a relatively high level of ownership; in Kampala in Uganda, for example, formal ownership of urban land for agriculture is 19.1% (see Table 6 in [72], p. 1674). It is mostly cultivated by women and is known to help improve child nutrition, in addition to obtaining higher levels of household food security. Indeed, some 34.8% of urban-dwellers in Kampala engage in some form of urban agriculture, including keeping livestock and cultivating crops (see his Table 3, p. 1671). Urban food production in this African city has been apparent since the mid-1970s during a time of "economic war." Maxwell et al. [73] investigated, more specifically, the impact of urban agriculture on children under five in Kampala and revealed that it is associated with their higher nutritional status, especially apparent in height for age.

It has been recently postulated that carbon sequestration has greater potential for food production on the urban fringe than conventional urban green spaces, such as parks and forests [74]. This conclusion is based on Life Cycle Assessment used to calculate the potential savings of food-related greenhouse gas emissions through urban community farming in the London Borough of Sutton, where farm design was found to have the greatest effect on savings. In populous cities located in the American Northeast, urban farms are smaller than conventional farms, but more plentiful at the urban fringe rather than in the urban core, where land costs are high [5]. These farms (in the American Northeast) are known to produce vegetables as well as eggs and goats.

Food production at the urban fringe (peri-urban agriculture) has the benefit of avoiding more polluted areas, as within the inner city. However, Agrawal et al. [75] monitored sulfur dioxide, nitrogen dioxide, and ozone conjunctive with plant responses and discovered reductions in a selection of parameters, including yield, for mung beans (*Vigna radiata*), palak (*Beta vulgaris*), wheat (*Triticum aestivum*), and mustard (*Brassica compestris*). This connects problems of air pollution (that are also connected with anthropogenic climate change) and urban crops, showing that gaseous pollutants can negatively impact crop yield, as witnessed in the case study of Varanasi, India. According to Metson et al. [76], it is possible to reduce phosphorus fluxes into cities (e.g., Phoenix, Arizona) by recycling waste and thereby diminishing dependency on external (rural) sources that may be polluting of aquatic systems. Urban soils are often untested for lead [77], and there are contingent implications for human health. Urban agriculture could also potentially act as a host and vector for the spread of pathogenic diseases [78], and possible negative effects (environmental impacts) should be considered as part of a cost-benefit analysis alongside positive aspects, including food security. This has been stressed as regarding carbon emissions from a primarily developed-world perspective offering lessons learned and best-practice advising to developing countries that are experiencing rapid rates of population growth and resource consumption. The use of graywater for urban agriculture leads to an annual infection (by enteric viruses) probability of > 10^{-4}, even following no irrigation with graywater for two weeks [79].

Based on 15 years of empirical evidence, Ellis and Sumberg [80] concluded that blurring the boundaries between urban, peri-urban, and rural areas does not solve the problem of food provision, as for the poor in developing countries for example sub-Saharan African cities and towns. It is likely that, as a land-based solution, urban agriculture is climate-dependent and cannot withstand these associated problems. An experimental approach should take into consideration climatic variables that can confound the role of urban food production for food security and urban sustainability. This would mean taking up spatial research methods; for example, as for examining the sociospatial structure of food production in Philadelphia, USA through remote sensing and GIS techniques [81], with climatic variables (e.g. water availability) integrated into datasets of land potential for urban food production. Moreover, Brinkmann et al. [82] demonstrated, through tracking changes in land cover via satellite imagery for the four African cities of Mali, Burkina-Faso, Nigeria, and Niger, that over the past 30 years irrigation water has influenced the expansion of cropland in the cities of Kano and Niamey contained within the semi-arid Sahel (although this was not the case for the cities of Sikasso and Bobo-Kioulasso in the Sudanian zone).

4. Critical review

Downing [83] identified four ways in which climate change will affect agriculture, through 1) the direct effects of increased concentrations of CO_2; 2) changes in climatic averages; 3) altered weather patterns, including extreme episodes; and 4) the indirect effects of social and economic systems. Research shows most vulnerability to the effects of climate change in Africa, the Horn of Africa, and parts of Asia. Appendini and Liverman [84] similarly considered economic internationalization (globalization) alongside environmental transformation, within the context of food security in Mexico. Likewise, Campbell et al. [85] suggested a greater focus on linking biophysical, social, and economic factors influencing future changes and consideration of the implications for food security. For instance, Chipanshi et al. [86] considered physical (e.g. lack of rain) and socioeconomic constraints on rain-fed crop production in Botswana, finding that the food security option then employed by the country was a good adaptive strategy.

Urban development has been found to greatly impact water use. For instance, Beijing's metropolitan area experienced reduced use of bluewater for crop production between 1990 and 2010 due to urban development. Current policies, however, aim to conserve agricultural land in order to achieve greater food security [87]. Nevertheless, it is possible to use urban vacant lots for gardening. For instance, considering three different scenarios (with varying amounts of area (vacant lots), crop yields, and human intake and given current policies and bylaws), Grewal and Grewal [88] tested land use for the city of Cleveland, USA. They ascertained that it was possible to attain overall self-reliance levels between 1.8 and 7.3% by expenditure in total (food and beverage) consumption in comparison with the current level of 0.1%. Their scenarios were as follows:

- Scenario I—utilizing 80% of vacant lots—generates 22–48% of Cleveland's demand for fruit and vegetables (in addition to 25% of poultry and shell eggs and 100% of honey), depending on gardening practice: conventional/ intensive/ hydroponic).
- Scenario II—adds 9% of occupied residential lots (to Scenario I), with a capacity for generating 31–68%of fresh produce (plus, 94% of poultry and shell eggs and 100% honey).
- Scenario III—adds 62% of industrial and commercial rooftop (to Scenario II), with potential to meet 46–100% of fresh produce (and 94% of poultry and shell eggs and 100% of honey).

These scenarios convey the high-generating capacity of food production in post-industrial North American cities, with potential to generate between 4.2 and 17.7% by weight. Globally, one-third of urban areas (regardless of suitability or availability) are required to meet the vegetable consumption of urbanites [89]. However, there are essential differences by location (among individual countries). China, Hong Kong, and Singapore have adopted urban food production, and cities like Shanghai, for instance, are known to be self-sufficient in the production of vegetables, most grains, and animal (pork, poultry, etc.) production [90]. Nevertheless, it has been suggested that large cities should not be the only focus for the development of urban agriculture, as smaller urban areas (each < 100 km^2) have the potential for space availability and represent some two-thirds of the global urban extent [88].

Recently, roughly 25–30% of urban-dwellers are involved in agrofoods globally (some 100–200 million urban farmers around the world, 65% of whom are women), and this level of participation is likely to grow as urban populations expand through the process of urbanization and with the persistence of rural-urban migration [91]. Burlington, Vermont, for instance, could meet 108% of its daily recommended minimum fruit intake under an ambitious planting scenario, so that urban food forestry remains a largely untapped resource (within a multifunctional landscape) to achieve urban sustainability [92]. New York City may likewise benefit from urban agriculture through the three pillars of sustainability: economically, socially, and environmentally [93], more specifically through the provision of healthful sustenance, inputs to household income (e.g., income generation in Lubumbashi, Democratic Republic of Congo [94]) and job creation as well as by offsetting food expenditures. Gardens and rooftop farms are known to foster social interaction and the development of common social and cultural identities in addition to the environmental benefits of reduced energy (as for food transport), reduced urban heat island effect, and stormwater mitigation. Community gardens can be found in areas where there is a low median household income [95], such as in immigrant neighborhoods located in San Jose, California [10].

Culture is one of the main differentiating elements of urban agriculture; for instance, Head et al. [96] discovered that Macedonian backyards where food was cultivated in (sub)urban Australia emphasized vegetable production and British gardens had native plants and exotic (non-native, ornamental) flowers, whereas Vietnamese backyards had more herbs and fruits. Gender has also been overlooked, and can impact what is cropped (type of foodstuffs) and even the quantity that is produced, as in Gaborone, Botswana [97]. Its potential can also be extended to vulnerable persons with HIV-AIDS, as in Nakuru, Kenya [98]. These authors recognized the strengthening of environmental, economic (financial), social, and technical capacities through urban agriculture.

5. Conclusion and recommendations

This review has addressed both the physical and human dimensions in the use of urban agriculture as an urban greening approach and mitigation-adaptation tool to climate change adaptation. It has considered both experimental findings and taken a global and integrated social-ecological perspective to addressing the issues. Specifically, the review has espoused that while urban agriculture has ecological benefits (as vegetation serves to capture and store carbon), it is also socially-affected and needs to operate within a social context. Such an integrated approach is increasingly popular in the recent literature addressing social-ecological systems and resilience (e.g., [99] for coasts). Another important dimension is disciplinary, with scientists working alongside social scientists to resolve real-world problems from a holistic (transdisciplinary, cf. [100])

perspective. More work of this nature is needed in order to realistically address pressing global environmental issues. Such problems are complex and should be approached from a diversity of perspectives that more realistically represents their actual milieus. Integrating physical findings with social contexts is necessary to derive feasible solutions, and recognizing that urban agriculture operates within a social context in addition to its physical dimension is already a step towards effectively working to achieving low carbon cities.

Conflict of Interest

None declared.

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