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Article (Published Version)

Nicholls, Elizabeth, Ely, Adrian, Birkin, Linda, Basu, Parthiba and Goulson, Dave (2020) The contribution of small-scale food production in urban areas to the sustainable development goals: a review and case study. *Sustainability Science*, 15. pp. 1585-1599. ISSN 1862-4065

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Exploring Interactions among the Sustainable Development Goals: Case Studies from Three Continents

The contribution of small-scale food production in urban areas to the sustainable development goals: a review and case study

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Received: 15 January 2019 / Accepted: 24 February 2020
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Abstract

Food production depends upon the adequate provision of underpinning ecosystem services, such as pollination. Paradoxically, conventional farming practices are undermining these services and resulting in degraded soils, polluted waters, greenhouse gas emissions and massive loss of biodiversity including declines in pollinators. In essence, farming is undermining the ecosystem services it relies upon. Finding alternative more sustainable ways to meet growing food demands which simultaneously support biodiversity is one of the biggest challenges facing humanity. Here, we review the potential of urban and peri-urban agriculture to contribute to sustainable food production, using the 17 sustainable development goals set by the United Nations General Assembly as a framework. We present new data from a case study of urban gardens and allotments in the city of Brighton and Hove, UK. Such urban and peri-urban landholdings tend to be small and labour-intensive, characterised by a high diversity of crops including perennials and annuals. Our data demonstrate that this type of agricultural system can be highly productive and that it has environmental and social advantages over industrial agriculture in that crops are usually produced using few synthetic inputs and are destined for local consumption. Overall, we conclude that food grown on small-scale areas in and near cities is making a significant contribution to feeding the world and that this type of agriculture is likely to be relatively favourable for some ecosystem services, such as supporting healthy soils. However, major knowledge gaps remain, for example with regard to productivity, economic and employment impacts, pesticide use and the implications for biodiversity.

Keywords Food security · Biodiversity · Urban farming · Agriculture · Pesticides

Handled by Joseph Alcamo, University of Sussex, United Kingdom.

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s11625-020-00792-z>) contains supplementary material, which is available to authorized users.

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Introduction

Agricultural systems depend upon the adequate provision of ecosystem services, such as pollination, biological pest control, maintenance of fertile soils, clean water and nutrient cycling and ensuring such food is produced in a safe, sustainable and climate resilient manner, adds considerably to the challenge. Current agricultural practices, particularly those associated with large-scale, industrial farming systems, are in fact one of the biggest drivers of environmental damage globally, resulting in degraded soils, freshwaters polluted with soil particles, pesticides and fertilizers, high greenhouse gas emissions and massive loss of biodiversity (West et al. 2014). In essence, farming is undermining the ecosystem services it relies upon, and hence a strong argument can be made that current practices are not sustainable. Finding ways to produce food which synergise with other

objectives, such as supporting ecosystem services, requires transformations involving technological, socio-economic and political changes (Marin et al. 2016) and represents one of the biggest challenges facing humanity in the twenty-first century (Rockström et al. 2017; Pretty et al. 2018).

The UN estimates that by 2050, 68% of the world's population will live in cities and urban areas, with rapid urbanisation most apparent in low to middle income countries (United Nations 2018). Producing food in urban and peri-urban areas is increasingly recognised as a potential strategy to meet at least part of the shift in food demands from rural to urban areas. In developed countries, urban agriculture can be an important coping strategy amongst poor households, contributing to food security and generating income (Thornton 2008). Many cities in developed countries have experienced a “local food” movement, which promotes small-scale, sustainable, local food production.

In our examination of the potential for small-scale agricultural production to contribute to the sustainable development goals, we begin by providing an introduction to the forms of urban and peri-urban agriculture and current estimates of the extent and productivity of urban food production. Using the sustainable development goals (SDGs) as a framework, we then examine the merits of urban and peri-urban agriculture as a contributor to global food security (SDG 2), and evaluate the relative impacts on other sustainable development goals, such as biodiversity and ecosystem services (SDG 15), poverty alleviation (SDG1) and climate action (SDG13), highlighting existing or potential trade-offs and synergies as compared to industrial farming (Sect. “Contributions to SDGs, synergies and trade-offs”). Lastly, we present a case study from the city of Brighton and

Hove in South East England, and the results of a two-year citizen science project, where urban growers across the city self-reported data on yields of insect-pollinated crops and pest-control methods (Sect. “Case study: urban agriculture in Brighton & Hove”). The SDGs are used to understand the relative benefits, costs, synergies and trade-offs between various pest-control methods used in urban agriculture, and to identify important areas for future research.

Forms and extent of urban/peri-urban agriculture

According to Tornaghi (2014) “urban agriculture is a broad term which describes food cultivation and animal husbandry on urban and peri-urban land”. There is no universally accepted definition differentiating urban and peri-urban agriculture, since in reality there is often a continuum from urban to rural (Marshall and Dolley 2019). Across this continuum, agriculture may take many forms, with a shift away from extensive practices common in rural areas, often mirroring the gradient towards more dense land use (and high land prices) in urban areas. The forms of urban agriculture described in Table 1 address very different food demands, display different commercial or non-profit models and have radically different implications for social and environmental costs and benefits. Whilst these distinctions are important, they have not been taken up widely in the literature. For that reason, the following review considers the extent of food production in urban and peri-urban areas without disaggregating across the different forms.

Globally it is estimated that there are 67.4 million hectares of urban croplands, comprising 5.9% of all cropped areas (Thebo et al. 2014). Ninety eight percent of urban

Table 1 Forms of urban/peri-urban agriculture (building on Lovell 2010; White and Stirling 2013)

Form of agriculture	Characteristics
Home gardens	Cultivation of food on privately owned land adjoining a residence
Allotment growing	Cultivation on small plots of land usually made available by the local authority—primarily hobbyist (non-commercial) in nature
Communal Growing/community gardens	Including community, confidence, welfare and skills. These spaces are typically open to the public, managed by groups of local people rather than by local authorities
Community-supported agriculture (CSA)	More commonly peri-urban/ rural, food is produced on a larger scale than in community gardens with more strongly delineated roles between growers and community members. Characterised by an exchange relationship that allows the risks of growing to be more equally shared than is the case in a typical producer–consumer relationship
Commercial	Food production for profit. Sale via a typical producer–consumer relationship (although produce is often sold into a supply chain rather than directly to end consumers)
Vertical agriculture	Integrating intensive farming into multi-use, multi-level urban structures, usually on a commercial basis
Edible landscaping	Incorporating edible fruiting trees, shrubs or herbaceous plants into the design of the residential landscape
Rooftop gardening	Cultivation of food crops on the roofs of domestic or commercial or municipal buildings
Informal urban agriculture	Opportunistic cultivation of food crops for sale or use on land that is not subject to strict land tenure enforcement, more prevalent in developing countries

areas with a population of greater than 50,000 people contain at least some urban cropland (Thebo et al. 2014). In a study of 15 developing countries, Zezza and Tasciotti (2008) found that between 10 and 70% of urban households participated in agricultural activities. Extrapolation from these data suggests that, globally, 266 million urban households are engaged in farming activities (Hamilton et al. 2013). Urban agriculture is more prevalent in East Asia, South Asia, and in developed countries (Thebo et al. 2014).

The above estimates exclude peri-urban agriculture taking place on the edge of urban areas; if a buffer of 10 km is placed around cities then this contains 34% of all croplands globally. Thus, cropland within and near cities likely comprises about 40% of the global total. Difficulties in accurately estimating the extent of peri-urban agriculture stem in part from the patchy distribution and ad hoc nature of this type of farming, with urban and peri-urban agriculture often not legally recognised as formal land use types (De Zeeuw et al. 2011).

Productivity of urban/peri-urban agriculture

Urban and peri-urban farms tend to be small, and while farmers may suffer from reduced economies of scale when compared to conventional farming, they can benefit from improved access to local markets and gain higher prices via short supply chains (Aubry et al. 2008; Jarosz 2008). In developed countries it has been observed that consumers increasingly prefer locally-produced food, particularly high quality and organic fruit and vegetable crops (Gilg and Battershill 1998).

Small farms can be equally, if not more, productive than industrial monoculture farming. This is particularly true if total output is considered rather than the yield from a single crop, given that in small-scale farming it is usual to grow multiple crops in the same space (inter-cropping) or within the same growing season. Of the 570 million farms worldwide, 84% are landholdings of less than 2 ha (Lowder et al. 2016). These small farms make up 12% of total agricultural area, yet produce 70% of food in Africa and Asia. In the United States the smallest two-hectare farms produced \$15,104 per hectare and netted about \$2902 per hectare. The largest farms, averaging 15,581 hectares, yielded \$249 per hectare and netted about \$52 per hectare (Altieri 2009). A recent study of UK organic farms smaller than 20 ha found them to be as productive and financially viable as conventional larger farms, despite being significantly less reliant on subsidies (Laughton 2017).

Despite the productivity of urban and peri-urban farms, Lovell (2010) highlights that given the competing demands on urban space and rising land prices ‘justifying the use of urban land for agriculture based on the production functions alone can be a challenge’. She suggests that urban growing

should be evaluated in terms of the multi-functionality of such land-use and the multiple services and benefits that can be provided. In the following section (see also Table 2) we have outlined these benefits and how they relate to the sustainable development goals (SDGs).

Contributions to SDGs, synergies and trade-offs

The Sustainable Development Goals (SDGs), agreed at the UN General Assembly in September 2015, represent an ambitious and universal agenda for sustainable development (UNGA 2015). They are a collection of 17 global goals, with an original set of 169 targets and each target possessing up to three indicators to measure progress to 2030. As a politically-defined set of goals, the SDGs do not provide a rigorous analytical framework for a study, such as this, however they are instructive as a heuristic for considering synergies and trade-offs across multiple objectives. Rather than taking a formal and systematic approach to identifying synergies and tensions between a small number of SDG targets (see, for example Weitz et al 2017), we have based the following section on published literature and organised it around the contribution of urban and peri-urban agriculture to food security, biodiversity and related targets at the level of the most relevant SDGs themselves. This section provides a summary of the contributions of urban agriculture to each goal, represented in a concise form in Table 2. Note that we do not include goals 4, 5, 6, 7, 9, 10, 14, 16 or 17 as the targets of these goals are not deemed to be directly impacted by urban agriculture.

Contributions to sustainable development goal 1 (no poverty)

Aside from the direct benefits of increased access to food, urban agriculture can increase income and alleviate poverty, either via the sale of surplus produce, or by reducing spending on food, which in the urban poor can represent a substantial proportion of household expenditure. As with the additional wellbeing benefits outlined in Table 2, it can often be hard to disentangle the health implications directly arising from improved nutrition from those associated with an increased income (Hamilton et al. 2013).

In addition to improving the income of growers, the sale of surplus food grown in urban and peri-urban areas has the potential to create jobs (Synergy with G8 Decent work and economic growth). Even at the level of household production for personal consumption, urban growing can liberate women from external employment, allowing them to improve childcare with positive implications for child health (Maxwell et al. 1998). Globally, the majority of urban

Table 2 Summary of the (potential) contributions of urban/peri-urban agriculture to sustainable development goal targets (selected on the basis of significant, direct impacts at the target level), and the synergies and trade-offs between goals

Sustainable development goal	Target (where relevant)	Direct contribution of urban/peri-urban agriculture to target	Synergies with	Trade-offs with
1. End poverty in all its forms everywhere		Provides income and/or alleviates need to purchase food	Job creation e.g. food vendors (G8)	
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	<p>2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round</p> <p>2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons</p> <p>2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment</p> <p>2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality</p>	<p>Increased access to diverse, nutritious food for urban residents</p> <p>Increased access to diverse, nutritious food for urban residents</p> <p>Urban agriculture can be highly productive (though this could be enhanced by support and advice), and is open to diverse sectors of society</p>	<p>Reduced food miles (G11, G13)</p> <p>Improved health and well-being (G3)</p> <p>Job creation e.g. food vendors (G8)</p>	
		Urban agriculture has the potential to be sustainable, productive, help cool cities and reduce flooding	Increased pollination and pest services (G2), improved access to green spaces (G11), improved climate resilience (G13), life on land (G15), Job creation (G1, G8), fewer emissions e.g. from synthetic fertilisers (G13)	

Table 2 (continued)

Sustainable development goal	Target (where relevant)	Direct contribution of urban/peri-urban agriculture to target	Synergies with	Trade-offs with
3. Ensure healthy lives and promote well-being for all at all ages	3.4 By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being	Direct health benefits from improved access to nutritious food, potential benefits to physical and mental health from physical activity and improved social interactions	Quality education (G4), sustained, inclusive and sustainable economic growth (G8)	Potential for exposure of poorly-trained and equipped urban farmers to pesticides
8. Promote sustained, Inclusive and sustainable economic growth, full and productive employment and decent work for all	8.3 Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises	Provides employment for growers and traders, and potential for growers to work cooperatively to achieve economies of scale and improve access to markets	Improve agricultural productivity and employment opportunities (G2)	Potential tensions with biodiversity (G15)
11. Make cities and human settlements inclusive, safe, resilient and sustainable	8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production 11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries	Urban agriculture can be both productive and low-input, as demonstrated in Brighton	Sustainable production and consumption (G12), water recycling (G6)	Competition with space for infrastructure, housing etc. (G9). Demands on drinking water for irrigation (G12)
12. Ensure sustainable consumption and production patterns	12.2 By 2030, achieve the sustainable management and efficient use of natural resources	Provides access to green space; cools cities; improves resilience to flooding Provides a sustainable form of food production; can utilise waste water for irrigation	Reduced pressure on rural land (G15) Reduced food miles (G13, G11) More sustainable cities (G11)	Health (G3) and environmental (G15) implications under conditions of <i>improper</i> waste management and <i>land contamination</i> from previous use
	12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses	Short food supply chain; potential for direct interaction between growers and consumers	Increased access resulting from greater supply (and lower cost) of food (G2)	

Table 2 (continued)

Sustainable development goal	Target (where relevant)	Direct contribution of urban/peri-urban agriculture to target	Synergies with	Trade-offs with
13. Take urgent action to combat climate change and its impacts	13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	Diversity and redundancy in food production and supply chains increases resilience	Resilient agricultural practices that strengthen climate change adaptation capacity (G2)	Potential for lower productivity (in the short-term) if low output agricultural approaches are adopted (G1, G2)
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	Boosts animal and plant biodiversity in cities	Improve climate resilience of the city e.g. storm attenuation, reduced heat island effect (G13), increased pollination and pest services (G2), improved access to green spaces (G11)	

farmers are in fact women (~65%, van Veenhuizen 2006); therefore, urban farming also contributes to the reduction of inequality and power imbalances between men and women (Synergy with G5 Gender Equality).

Contributions to sustainable development goal 2: zero hunger

The primary benefit of urban farming is the provision of nutritious food. In many cities there exist 'food deserts', where retailers of fresh produce, including supermarkets, have been replaced by convenience stores selling processed foods (Thomas 2010; ver Ploeg et al. 2009) limiting access to nutritious food. A review by Zezza and Tasciotti (2010) of urban agriculture in developing countries showed that households involved in farming or gardening had better access to food, a more diverse diet and ate more vegetables than households not involved in farming.

In some cities, a large proportion of fresh food demands may be met through urban agriculture. In Shanghai, for example, which has a population of 24 million people, 60% of all vegetables consumed within the city (and 90% of eggs) are produced within the city (Lovell 2010). Fresh foods grown in urban areas can typically be consumed more rapidly post-harvest, which also improves nutritional content (Shewfelt 1990).

A systematic global review by Berti et al. (2004) showed that, of all agricultural interventions studied, home gardening was the most successful in improving nutrition. However, a systematic review of studies examining the nutritional outcomes specifically for children under 5 (Masset et al. 2011) found that, while home gardening improved the production of food, in general there was no difference in nutritional outcomes for children, meaning the relationship between urban growing and nutrition may vary considerably across cities and demographic groups. More rigorous assessments of the nutritional benefits of peri-urban agriculture are certainly needed, not least to provide an evidence base for local authorities in designating land use priorities.

Improved nutrition can also lead to better mitigation of disease (Synergy with G3 Good Health and Wellbeing, Lock and de Zeeuw et al. 2001). Over one billion people worldwide are overweight or obese, and this is not simply a concern for developed countries. For example in South America the lack of access to fresh food means that many people consume cheap highly calorific food instead (Fraser 2005). Both the World Health Organisation and Public Health England recommend increased consumption of fruit and vegetables and reduced consumption of meat, dairy and processed foods as vital in tackling the global obesity epidemic. Indeed, a recent global analysis comparing agricultural production to recommended dietary intake, suggests that conventional agriculture currently overproduces grains, fats and sugar,

while underproducing fruit, vegetables and sources of protein (Krishna Bahadur et al. 2018). The report suggests that correcting this imbalance would reduce the area of arable land required by 51 million ha, but that the total area of land under cultivation would need to increase by 407 million ha. The report explicitly highlights the potential for urban agriculture to contribute to meeting such demands.

SDG Target 2.4 calls for sustainable food production systems. As discussed previously, urban agriculture typically involves more agro-ecological methods of production and more labour, but less use of synthetic fertilisers and pesticides, the production of which account for a large proportion of greenhouse gas emissions associated with farming (Synergy with G13 Climate Action, Lal 2004; US Environmental Protection Agency 2006), and contribute to environmental pollution and harm to wildlife (Synergy with G15 Life on Land, Pisa et al. 2017). In the UK, crops on conventional farms receive an average of 17.4 pesticide applications (Goulson et al. 2018). In contrast, peri-urban and urban food growers in the UK are often organic (Ilbery et al. 1999). Only 2.9% of the area of UK farmland is organic (Defra 2017), while in contrast a 2013 survey by the Health and Safety Executive, UK, found that 30% of gardeners used no pesticides (Resource Futures 2013). Similarly, Voight et al. (2017) surveyed the environmental behaviour of urban allotment gardeners across Europe and found that only a very small proportion of respondents (0–6% across each region) used pesticides regularly. Considering those regions with more than 100 respondents, between 20 and 54% used pesticides sometimes, while 42–54% never used them. However, there remains no systematically-collected data on pesticide use on peri-urban and urban crops, so we cannot adequately compare overall use to conventional farming or discern trends in pesticide use.

Contributions to sustainable development goal 3 (health)

Beyond improving access to more nutritious food, urban agriculture can also improve the physical health of growers through the exertion involved in cultivation and harvesting, and mental health can be maintained through an improved connection to nature and increased community cohesion (Wakefield et al. 2007; Clatworthy et al. 2013; Hawkins et al. 2013). For example, it has been found in the Netherlands that allotment holders are healthier than their neighbours without allotments, although this was only significant for those over the age of 62 (van den Berg et al. 2010). There is also evidence of more diffuse benefits of urban farming beyond those that grow and consume the food, since the simple presence of greenspace in cities is also positively associated with human health (Groenewegen et al. 2012).

Although there are potential health benefits from urban agriculture, there are also risks. Where pesticides are used, urban farmers and gardeners often have no training in how to use them safely. In developing countries the chemicals used are often banned or heavily restricted in the developed world (Polder et al. 2016), with implications for both human (Trade-off with G3 Good Health and Wellbeing) and environmental health (Trade-off with G15 Life on Land). For example, screening of lettuce grown in urban and peri-urban smallholdings in Ghana and sold in local markets found that 78% contained the organophosphate chlorpyrifos, and 31% contained the organochloride lindane (Amoah et al. 2006). Both are chemicals that are harmful to human health and lindane in particular has been banned for use in most countries for many years. A recent ‘Unearthed’ investigation by the NGO Greenpeace revealed that it is currently possible for UK growers to purchase unauthorised pesticides or herbicides online via sites, such as ebay.co.uk, including atrazine, a herbicide which has been banned for sale in the EU for more than a decade (Sandler-Clarke and Dowler 2018).

Growing food in close proximity to cities also runs the risk that it may be contaminated with pollutants less likely to be found in rural areas. For example, harmful levels of heavy metals have been found in 36% of leafy vegetables originating from peri-urban farms in Kampala, Uganda (Nabulo et al. 2012). Similarly, phthalate esters have been found in agricultural soils close to urban areas in Guangzhou, China (Zeng et al. 2008). In general, our understanding of the extent to which contaminants are absorbed by the gut is poor and requires further research (Leake et al. 2009). However, in England at least, assessments by the Food Standards Agency of soil and crop contamination of 94 allotment and garden sites across nine towns and cities concluded that the food grown in these sites is safe to eat (Food Standards Agency 2006, 2007). For example, while lead contamination was more than five times higher than in rural areas, less than 1% of harvested food samples analysed exceeded the statutory limit of 1 mg per kg of fresh weight (Food Standards Agency 2007). Nevertheless prior land-use and the impact of air pollution should be considered in planning of future sites for agricultural use in cities.

Contributions to sustainable development goal 8 (decent work and economic growth)

In Shanghai alone 2.7 million people are peri-urban farmers (Yi-Zhong and Zhagen 2000), while globally an estimated 266 million urban households are engaged in peri-urban farming activities (Hamilton et al. 2013). In operations beyond production for personal consumption, peri-urban agriculture can create jobs for farm labourers, food transporters and food vendors, although we are unaware of any estimates as to the numbers of people involved. Horticulture

is particularly labour intensive; for example in the UK 12% of the agricultural workforce are employed in horticultural cultivation despite it comprising just 3.5% of total agricultural land (van Berkum et al. 2016).

Contributions to sustainable development goal 11 (sustainable cities and communities)

The multiple social benefits of urban agriculture (especially communal growing but also related activities, such as home gardens, allotments and community supported agriculture) include therapeutic and health benefits to those involved, as well as the opportunity to build social skills and community networks (White and Stirling 2013). These all link with target 11.7, which calls for improved access to green spaces, and has synergies with SDG 4 (discussed above). Growing food in cities may lead to reduced pressure on rural land (synergistic with SDG 15), and reduced food miles (synergistic with SDG13 and SDG11). However, it can also compete with space for infrastructure and housing (SDG 9).

Contributions to sustainable development goal 12 (responsible production and consumption)

The proximity to large areas of dwellings means that urban agriculture can make sustainable use of wastewater and solid waste in the production of food, which can minimise conflicts over freshwater use in cities, and reduce the demand for water in food production in general. This is of particular importance in areas where water may be scarce, thus improving the resilience of food production to extreme climatic events, such as droughts (G15). Recycling of waste into food production can reduce the costs of public waste management and help to minimise urban run-off and pollution of pristine land and freshwater supplies (Buechler et al. 2006, G11). In developing countries in particular, urban waste contains a high proportion of organic material, which can be substituted for synthetic fertilisers which are expensive and energetically costly to make (G13, De Zeeuw et al. 2011). The ready access to such cheap sources of nutrients can provide urban growers with an economic advantage over rural counterparts (De Zeeuw et al. 2011), though within some cities competition over such resources is growing (Bunting et al. 2010).

Improper use of wastewater or solid waste can nonetheless raise concerns regarding public health safety, given the potential for increasing the spread of disease (Trade-off with G3). This is of particular concern for those crops, such as fruit and salad crops that are typically eaten without cooking (Amponsah-Doku 2010). However, a number of simple, low-cost interventions are available that can minimise this risk, such as the use of sedimentation ponds, or irrigation

methods that avoid contact with the edible parts of the crop (Rojas-Valencia et al. 2011).

Contributions to Sustainable Development Goal 13 (Climate Action)

In addition to the health and wellbeing benefits, green areas in and close to cities help to reduce warming (Drescher et al. 2006; Susca et al. 2011) and air pollution (Lwasa et al. 2014), protecting urban areas from extreme climatic events (Synergy with G13; Climate Action). However, there have been very few attempts to quantify the specific impacts of urban and peri-urban farming on climate (Pataki et al. 2011). For example, there is potential for carbon capture into crops or soil, but to our knowledge this has not been investigated in detail. Soil organic carbon was found to be 82% higher in urban “herbaceous” areas compared to rural arable land in a study in Leicester, UK (Edmondson et al. 2014). Since natural ecosystems capture more carbon than cropland (Wei et al. 2014), by reducing the pressure to convert more pristine areas to agricultural production, urban agriculture may contribute to climate action indirectly as well. In addition, in conventional farming often significantly more energy is used in transporting food from the farm to the consumer than in the growing process itself (Heinberg and Bomford 2009), and so growing food in close proximity to consumers can reduce emissions during transport (Paxton 1994). However, this remains a widely debated issue, with some arguing that growing food in urban locations may incur higher production costs through the use of fertilisers or heated greenhouses (e.g. Blanke and Burdick 2005). However careful crop selection and the integration of greenhouses into existing buildings can reduce energy consumption by over 40% (Delor 2011).

Contributions to sustainable development goal 15 (life on land)

Peri-urban agriculture can contribute to the preservation of life on land in two principle ways; (1) through the creation of wildlife habitat in urban areas and (2) by reducing the pressure to further intensify and extend agricultural production in rural areas. In general, urban areas have limited levels of biodiversity (Lin and Fuller 2013); however, the rich plant diversity deliberately cultivated in urban gardens and allotments (Colding et al. 2006; Bernholt et al. 2009; Matthies et al. 2015; Borysiak et al. 2017) can provide food and habitat for other wildlife, such as birds and insects (Quesada and MacGregor-Fors 2010; Lin et al. 2015). A recent comparison of habitats across four UK cities found allotment and residential gardens to be ‘hotspots’ for pollinators (Baldock et al. 2019) and Samuelson et al. (2018) found that bumblebee colonies grow larger and produce more reproductive

offspring in urban areas compared to rural areas. The increased plant and animal diversity in urban areas resulting from agriculture can also lead to an increase in the provision of ecosystem services, such as pollination and pest control, which are vital for food production (Synergy with G2; Zero Hunger). Comparatively little is known about the extent of these services within urban agriculture (Lin et al. 2015), but a recent analysis of the multifunctional benefits of urban agriculture estimates the services provided by current vegetation in terms of biocontrol, pollination, climate regulation and soil formation, to be worth approximately \$33 billion USD annually (Clinton et al. 2018).

Although urban areas have the potential to support biodiversity, this depends how they are managed and what pesticides are applied to them. Without adequate training of urban farmers, pesticides might be applied inappropriately, for example at the wrong rates or wrong time of day (e.g. if insecticides are sprayed on flowering crops when bees are active), potentially rendering them ineffective and/or far more harmful to human health and the environment (Dinham and Malik 2003). It is widely recognised that pollinators are declining, and that pesticides use in conventional farming is a contributing factor (Goulson et al. 2015), yet the impact of pesticides in urban areas is much less well studied. Recent studies comparing exposure of bees in rural and urban areas of the UK have found bees in urban areas are indeed exposed to pesticides, often at comparable levels to bees in rural areas (Nicholls et al. 2018). Awareness of potential risks to human and environmental health is key, as is disseminating information about alternative pest control methods, such as agro-ecological methods.

Case study: urban agriculture In Brighton and Hove

Context of the case study

Brighton and Hove is a coastal city in South East England, approximately 50 miles from London, with a population of 273,369 (United Kingdom census 2011). The city benefits from an established Food Partnership, a multi-stakeholder platform which was founded in 2003 and developed the first city food strategy in 2006. This has since been refreshed in 2012, with the most recent food strategy and action plan released in 2018. This envisions a “healthy, sustainable and fair” food system and has been accompanied by a monitoring and evaluation plan (aligned with the SDGs where appropriate) through to 2023 (BHFP 2018).

Whilst the city includes some of the most affluent parts of the country (DCLG 2015), it also hosts some of the most deprived, and significant food poverty exists. Two recent local authority-commissioned surveys indicated that

8% of the city’s population ‘strongly disagree’ that they can meet their basic living costs, including food, water and heating (City Tracker 2017, 2018). In 2018 there were 17 food banks in the city together supplying 358 parcels per week (an increase of 25% on 2014 numbers) (BHFP 2018). In Brighton and Hove alone, the NHS spends close to £80 million. per year tackling diet-related diseases, and 30% of children aged 10–11 are obese (BHFP 2018).

Urban agriculture, in particular communal growing is seen as a partial response to some of these problems (White and Stirling 2013) and over 75 communal growing projects currently exist across the city (BHFP 2018). A 3-year community gardening scheme, ‘Sharing the Harvest’, co-ordinated by Brighton and Hove Food Partnership provides direct evidence of the additional health and well-being benefits of food growing in the city (SDG 3). The scheme engaged 2000 vulnerable adults in the city, and an independent assessment of the project by the University of Essex found that 97% of participants surveyed reported increases in their mental wellbeing, and 89% reported an increase in physical fitness (Rogerson et al. 2017).

According to the city allotment strategy, published in 2014, there are 6,000 allotment growers in the city of Brighton and Hove (~2% population), farming 3100 plots over 37 sites. In total, allotments cover an area of approximately 50 ha, and an unknown proportion of home gardens are also used to produce food. Demand for urban growing space is high, with 1000 people on the waiting list for a plot, and an average wait time of 2 years (Brighton and Hove Allotment Strategy 2014). The city also benefits from community-supported commercial production on the 40,000 Ha Downland Estate on the peri-urban fringe (owned by the local authority). Rooftop gardening has increased following the production of a Planning Advisory note on including food growing in new developments, thus helping to embed good practices into policy (Durrant et al 2018), resonating with SDG11’s call for integrated and sustainable human settlement planning and management.

A pilot study on agricultural practices in allotments and home gardens

Building on existing information and in order to address the paucity of data on both the productivity and environmental impacts of small-scale urban agriculture, we conducted a 2-year pilot study to assess how particular approaches to urban agriculture in allotments and home gardens in cities might contribute to food security (SDG2) and enhance biodiversity (SDG15). The pilot aimed to answer the following questions:

1. How much food can be produced in a typical urban garden or allotment?
2. What pest control methods are used most frequently by urban growers?
3. What value do pollinators add to urban agriculture?

This study is therefore particularly relevant to SDG2 (e.g. towards more productive, sustainable food production systems and resilient agricultural practices). Beyond this, the data we collected provides insights that can inform improved sustainability in this particular context (e.g. the importance of specific pollinators), and can enhance our understanding of the conditions underlying SDG15 (in particular the relative impacts of agricultural practices on pollination services, relevant to target 15.1).

Methods

Given the lack of statutory monitoring of urban growing and agro-chemical use, a ‘citizen science’ methodology was adopted which involved growers self-reporting yields and agro-chemical use. This was hypothesised to be the most robust method for obtaining data at the level of individual allotments and private gardens, particularly since access is largely restricted. Therefore, another aim of the pilot was to develop a simple methodology that urban growers with little to no formal scientific training could use to collect data on crop yields, pest control methods and pollinating insects in their own growing spaces.

The pilot ran from April 2017 to October 2018. During this time we recruited 185 allotment-holders and home-growers via posters at allotment sites, email lists, social media and community gardening-themed events. Once enrolled in the programme, participants received a data collection pack in the post and were added to our e-mailing list to receive monthly updates on the project. They were invited to attend a training session on how to collect data in their growing space.

Participants were instructed to conduct surveys of insects visiting their flowering crops twice a month throughout the growing season (April–October). They were also instructed to record any pests or diseases encountered in their plots and the control method they used, if any (e.g. insecticide

spray, slug pellets, no action). Lastly participants were asked to record the weight (or number of items) of each insect-pollinated crop harvested from their growing space.

As well as paper recording sheets, participants also had access to a ‘Garden Calculator’ spreadsheet (see Supplementary Materials) which they could download from the project website. The spreadsheet permitted volunteers to record the weight or number of food items harvested from each crop and then calculate the cost to purchase the equivalent amount from a shop (predominantly Waitrose Ltd., Bracknell UK, but also Abel & Cole Ltd., Wimbledon, UK for less commercially available crops. Prices were obtained from the shop’s websites and updated for each year of the study. See Supplementary Materials). Using published values of the pollinator dependency of each crop, the spreadsheet also calculated the proportion of the total harvest that resulted directly from insect pollination, presented in the form of a pie-chart, and the monetary value that was ‘owed’ to pollinators (i.e. the cost of the produce that depended on insect pollination).

Findings

The average size of a participants growing space was 175 m² (range 1 m²–500 m²). On average, individuals produced 73.56 kg (\pm SD 75.82 kg, min = 3.1 kg, max = 251.5 kg) from their growing space which, accounting for the different sizes of growers’ plots and gardens, translates to an average of 1 kg (\pm 2.41 kg) of fresh produce per m² of growing space (10 tonne/ha), with some growers producing up to 9.68 kg/m² (96.8 tonne/ha) [and note that this is only crops requiring pollination, and so excludes some high-yielding crops, such as potatoes]. For a breakdown of harvest weight and yield by crop type, see Table 3. All food was produced with limited pesticide use, with resultant benefits to SDG 15. Indeed, less than 4% of growers who participated in the citizen science pilot used non-organic insecticide sprays. Slug pellets were used by 58% of growers.

Converting these yields into the cost of buying organic produce from a supermarket, the maximum reported value of an annual harvest was £2300, with home-growers ‘saving’, on average, £550 per year. Accounting for the extent to which each crop is reliant on pollination, on average, £310

Table 3 Mean yields by crop type (tonnes/hectare \pm standard deviation) based on 160 submitted crop harvests, from 33 citizen scientist participants over two growing seasons (2017–2018)

Crop type	Mean yield (t/ha) \pm SD	N harvests
Legumes (Broad beans, runner beans)	1.73 \pm 6.94	20
Cucurbits (Squash, pumpkin, cucumber, melon)	0.86 \pm 1.21	31
Capsicum (Chilli pepper, bell pepper)	0.02 \pm 0.05	10
Soft fruits (Berries, currants)	0.21 \pm 0.49	68
Top fruits (Apples, pears, plums)	0.21 \pm 0.27	18
Tomatoes	4.63 \pm 12.71	13

worth of produce was directly ‘owed’ to insect pollinators, per grower, per year. For a break-down of crop value and ‘pollinator value’ by crop type, see Fig. 1. Clearly pollination is vital to urban agriculture. However, since we do not have data on pollinator populations in urban and peri-urban settings in either developed or developing countries, it is unclear whether current populations of pollinators in these areas are sufficient to provide adequate pollination to maximise crop yields. This is something we plan to investigate experimentally in the future, by comparing the yields of plants receiving supplementary hand-pollination to those receiving visits from insects alone to test whether a pollinator deficit exists in urban growing spaces.

This case study illustrates, for the first time, the mass and value of food that can be produced from urban agriculture in a city, such as Brighton and Hove, and the proportion of that value provided by pollinators. Within the context of a medium-sized European city, it shows the contribution of urban agriculture in communal gardens, allotments and home gardens to several interacting SDGs. The economic extrapolations of the project are also instructive, lending support to urban agriculture at an individual level. However further research on the cost of labour inputs (related to SDG 8), equality of participation (SDG10) and other goals would be required to provide a full understanding of these phenomena within the entire food system of Brighton and Hove.

Conclusions

Compared to conventional, industrial farming, peri-urban agriculture has been the subject of little research and is often not formally monitored by government agencies,

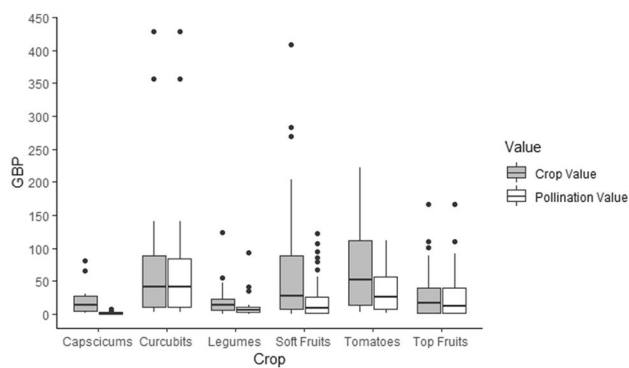


Fig. 1 Value of crop harvest in GBP (grey bars) based on 2018 supermarket prices (see Supplementary Materials) and the value of the pollination service delivered by insects (white bars), by crop type. Data consists of 160 crop harvests submitted by 33 citizen scientists. Box limits denote the first and third quartiles, and boxplot whiskers extend to 1.5 times the interquartile range. Outliers are represented by solid black circles

so that numerous knowledge gaps remain (Thornton 2008). Therefore, our pilot study conducted in the city of Brighton and Hove provides a useful case study to examine the potential for urban agriculture to contribute to sustainable development. We found that home-growers in the city use few agro-chemicals and yet can have crop yields comparable to or higher than those from large-scale conventional farms. This suggests that urban growing has the potential not only to contribute to food security in the city (SDG2), but that it may also be more beneficial to environmental (SDG15) and human (SDG3) health as compared to current industrial practices.

The use of a citizen science methodology permitted us to collect data at a city-wide level, and such methods could easily be applied to other urban contexts. Indeed, our methods are currently being utilised to examine the contribution of urban and peri-urban agriculture to food security and potential impacts on biodiversity in the city of Kolkata, India. Nevertheless, larger scale and ideally long-term studies are needed to fully evaluate the extent to which urban agriculture can contribute to sustainable food production on a global scale.

Despite limited data, urban agriculture is recommended as a contributory solution to alleviating hunger by reports published by the FAO, World Bank and the UN High Level Task Force on the Global Food Crisis but unfortunately it is often met with apathy by local governments or even actively discouraged by authorities trying to portray a more progressive city image (Hamilton et al. 2013). Therefore, more concrete evidence of benefits is needed to convince government officials of the benefits of urban growing. Our study goes some way towards delivering this evidence.

Historically, urban agriculture has been formally supported by governments in response to crises (e.g. world wars in UK and US, the blockade in Cuba). In future such schemes could be better integrated into city plans to make sure that it is possible to take full advantage of the synergies between the sustainable development goals. Overall, such agriculture production has the potential to reduce poverty and hunger and improve health outcomes for people, while simultaneously reducing pressure on the natural environment and improving climate resilience. A recent analysis by Clinton et al. (2018) estimated the potential of future urban agricultural expansion to provide \$80–160 USD billion worth of food and ecosystem services annually. For this to be achieved, more monitoring, regulation, support and advice for growers is needed. Whilst this pilot study brings new evidence to the wider review contained in this paper, a better evidence base is needed if the potential SDG benefits, synergies and tensions associated with urban agriculture are to be understood and realised in Brighton and Hove and elsewhere.

Acknowledgements We are grateful to the Sussex Sustainability Research Programme for funding this work, and to the home-growers for sharing data on crop yields and pesticide use. We thank Helena Howe and Pedram Rowhani for useful discussions on the topic of peri-urban farming.

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