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The hidden potential of urban horticulture

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Urban areas offer considerable potential for horticultural food production, but questions remain about the availability of space to expand urban horticulture and how to sustainably integrate it into the existing urban fabric. We explore this through a case study which shows that, for a UK city, the space potentially available equates to more than four times the current per capita footprint of commercial horticulture. Results indicate that there is more than enough urban land available within the city to meet the fruit and vegetable requirements of its population. Building on this case study, we also propose a generic conceptual framework that identifies key scientific, engineering and socio-economic challenges to, and opportunities for, the realization of untapped urban horticultural potential.

Food insecurity is a growing issue in the Global North[1,2], where the majority of the population (sometimes in excess of 80%) lives in urban areas[3]. Food production in urban areas, particularly horticultural production[4,5], is increasingly recognized at all levels of governance, from local to transnational, as an important contributor to food security[6]. Despite this recognition, there have been few attempts to analyse the feasibility of urban horticulture (UH) in terms of the space available within the urban fabric.

We explore this issue in a case study city in the United Kingdom using a geographic information system (GIS) to map green infrastructure now used for UH along with other green infrastructure (such as parks, gardens, roadside verges and woodland) and grey infrastructure (buildings, for example) that has the potential to form part of an expanding UH system. We then develop a conceptual framework that addresses the scientific, practical engineering, knowledge, economic and socio-cultural factors that underpin sustainable UH delivery in the Global North. Within this framework, we consider two different forms of UH: soil-based horticulture (SBH) within green infrastructure and controlled environment horticulture (CEH) on flat roofs within grey infrastructure.

Is there space to grow?

In the United Kingdom, approximately 16,000 km^2 of land is designated as urban[7], of which green infrastructure constitutes approximately 50% (refs. [8–10]) (an area 5.3 times larger than that used nationally for the commercial production of fruits and vegetables[11]). To understand the extent to which UH can make use of this apparent land resource, we used high-spatial-resolution datasets (specifically Ordnance Survey MasterMap and Google Earth Imagery) in a GIS to analyse the current and potential productive space for UH for the UK city of Sheffield. With 582,500 inhabitants[12], Sheffield has the sixth largest population in England and Wales[13]. As is typical of larger urban areas, it is among the most deprived 25% of local authorities in the country[14], indicating that considerable levels of food insecurity are likely[15]. Sheffield (as defined by the local authority boundary) covers an area of 36,800 ha, of which 22,700 ha are urban or peri-urban, comprising green and grey infrastructure — the focus of this study. Green infrastructure, including all green space within the city, covers 10,600 ha (45%; Fig. 1a), similar to other UK cities[8–10]. Urban allotments (that is, rented plots used specifically for horticultural production by individuals or households) are, in terms of area, one of the main resources for UH in Europe, with legal requirements in the United Kingdom and some other European countries for local authorities to provide allotment land[16]. Allotment land in Sheffield comprises 1.3% of green infrastructure, with a further 38% as domestic gardens (Fig. 1b). These areas of land are either in use or, in the case of domestic gardens, have the immediate potential to be managed by individuals for SBH. We used a set of spatial restriction criteria in a GIS (for detail see McHugh et al.[17] and Grafius et al.[18]) to identify parcels of land within the wider green infrastructure of the city potentially suitable, but not currently used, for SBH. These parcels of land were split into community garden spaces, representing smaller land parcels where communities have open access to land for UH (parcel sizes range from 600 to 2,999 m^2) and allotment spaces, which are larger patches of land composed of groups of allotment plots (250 m^2 average size) rented to an individual or household[16] (parcel size>3,000 m^2). We thereby identified an additional 1,192 ha (11%) of green infrastructure that is potentially suitable for allotment-style growing (Fig. 1b) and 404 ha (4%) for community garden-style growing (Fig. 1b). Together, this represents 98 m^2 per person in Sheffield: 71 m^2 in domestic gardens and allotments and 27 m^2 in the wider green infrastructure. This is an upper estimate, given that not all identified land would be usable in practice, and cultivation of smaller parcels (such as domestic gardens) may be subject to disproportionate losses to infrastructure (access, storage). Yet, effective utilization of less than one-quarter of this area would equal the 23 m^2 per capita[11] nationally used for UK commercial horticultural production of fruits and vegetables.

Recent developments in soil-free intensive CEH (such as hydroponics and aquaponics for high-value, high-yield crops) may facilitate the utilization of grey infrastructure within and on top of buildings. We investigated the potential area of flat roofs for UH, as they could allow year-round cultivation with minimal lighting requirements using greenhouses with rainwater harvesting for irrigation — although their areal extent is not well known. Green infrastructure is

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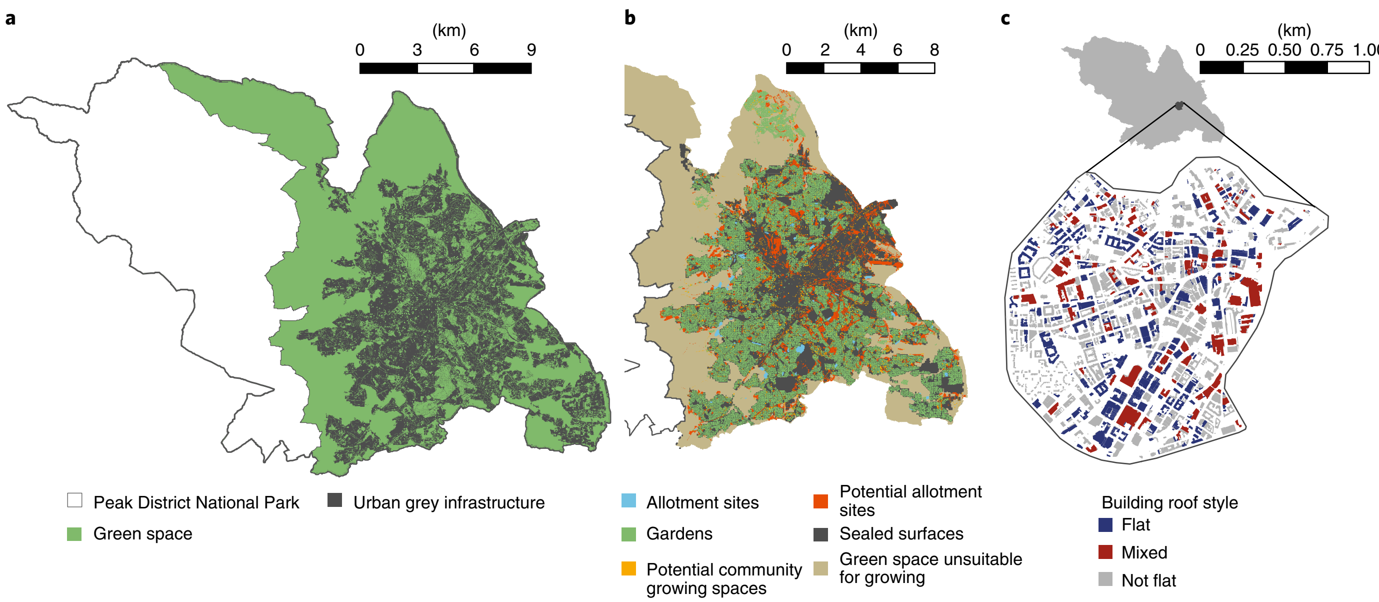

Fig. 1 | The city of Sheffield. a, Current land-use within the local authority boundary. **b**, Current land available and green infrastructure suitable for UH. **c**, Grey infrastructure with flat roofs potentially suitable for UH within the city centre.

predominantly situated in the suburbs, yet the commercial city centre covers 229 ha with buildings comprising 58% of the area (Fig. 1c), while flat roofs cover 24% (32 ha) of this building area (Fig. 1c). As with expansion into green infrastructure, not all flat roofs would be useable for CEH in practice, so this value is a maximum. Although this area equates to just 0.5 m^2 per person, the high-yielding nature of CEH production systems and focus on specific crop types could nonetheless contribute substantially to the city-wide UH potential[19].

We therefore conclude that there is ample space in our case study city to expand UH, with 98 m^2 per capita in green infrastructure augmented by small, but potentially highly productive, CEH space. This adds to the growing evidence that this important land resource could be made available for UH[20–23] and that, at a global scale, urban land area would be more than sufficient to meet the vegetable demands of urban populations[24].

The potential of UH

As shown in an earlier study focused on the UK city of Leicester, allotments can potentially produce enough fruits and vegetables to feed 3% of the population per year on a recommended 'five a day' diet (400 g per day)[25] based on an average yield across all allotment land of 1.8 kg m^{-2} yr^{-1} (ref. [26]). Using this same yield, we estimate that allotment holders in Sheffield are also potentially feeding about 3% of the city's population their '5 a day' diet. But how much more could be grown by SBH? Across the city, the area of existing allotments and domestic gardens, and potential new allotment and community garden sites, covered 5,752 ha; if 100% of this land was used for SBH, this could feed approximately 709,000 people per year on their '5 a day' diet, or 122% of the population of Sheffield. More realistically, if SBH was practiced in 10% of domestic gardens and expanded into 10% of the additional land identified in the GIS, it could feed 12% of Sheffield's population per year (15% in total including allotment land now in use).

While the availability of space is one constraint for SBH, effective cultivation at the scale of an allotment or garden is also labour-intensive; allotment holders spend on average 190 h yr^{-1}, over 55 visits, to cultivate a 250 m^2 allotment plot (Fig. 2)[27–34]. Realizing SBH production at the 10% level would equate to about 3.5 million h yr^{-1}. If carried out by 10% of the population, this would represent around 60 h per person per year.

The potential of CEH presents a different challenge to estimate. While the figures used above for SBH cover the full range of crops grown across the year, CEH systems focus on producing a smaller number of high-value, high-yield crops[19]. Here we use tomato as an example of a high-yield crop to illustrate the potential of CEH in our case study city, as the United Kingdom imports 86% of its total tomato supply at present (and this crop alone accounts for 21% of the value of all vegetable crops imported to the United Kingdom[11]). If only 10% of the flat roofs identified within the centre of Sheffield were used for CEH, assuming a tomato yield of 42.9 kg m^{-2} yr^{-1} (the average yield of hydroponically grown tomato[35]), it would be possible to grow enough tomatoes to feed nearly 2% of the population per year on a 'five a day' diet. This increases to 12% if 75% of the flat roof area is utilized for CEH. Overall, there is considerable production potential for SBH to cover the fruit and vegetable demand of the entire city's population, as well as important (though smaller) potential for CEH to contribute, especially if used for high-yielding crops. However, much more work is needed to fully understand the extent to which this potential can be realized.

A framework for the sustainable expansion of UH

Fulfilling the potential of UH requires an understanding of the range of scientific, practical engineering, knowledge, economic and socio-cultural factors that may influence its extent, effectiveness and sustainability (Fig. 2). Many of the challenges related to CEH are technological, such as developing sustainable growing media, automated Internet of Things control and monitoring devices linked to the wider availability of low-power wide-area networks (LPWAN), as well as the architectural and engineering challenges of deployment on current building infrastructure. Furthermore, for sustainable and efficient running of these systems, they should capture heat from buildings, use renewable energy and obtain water from sustainable sources, such as rainwater harvesting. The economics of UH are not simple, enmeshed as they are with the fact that much UH is not commercial at present. Nonetheless, attention to economic issues, — whether cheap growing space to support non-commercial production, or a focus on high-value crops in commercial production (particularly CEH) — clearly has an important role in encouraging UH expansion. A better understanding of

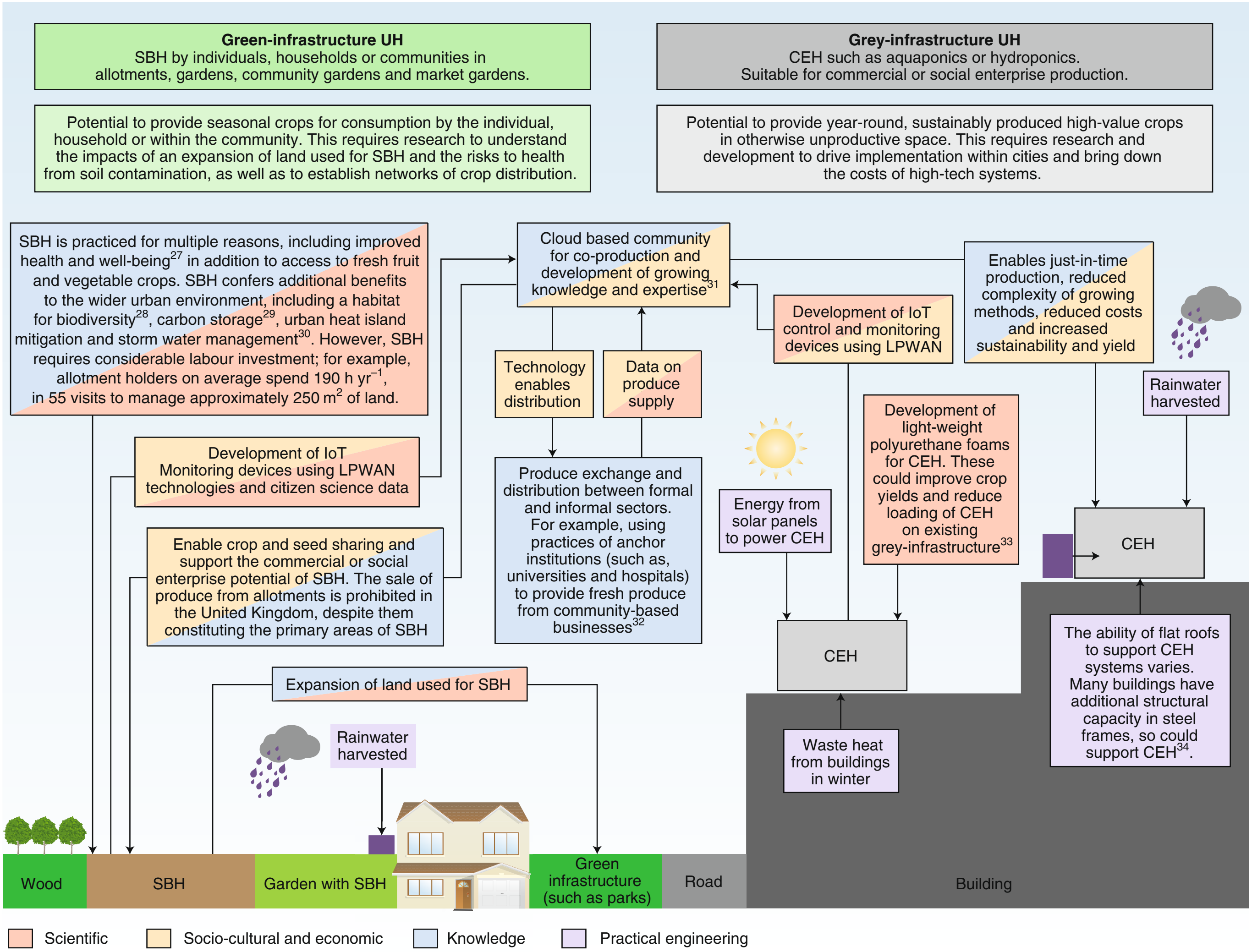

Fig. 2 | Conceptual framework for the expansion of urban horticulture. The implementation of an urban agricultural system may involve scientific, socio-economic, practical engineering and knowledge-based challenges.

the suitability of different crop species and varieties for both CEH and SBH would help to realize these goals.

One area of rapid change is knowledge dissemination. Mobile and digital technologies enable immediate knowledge sharing and facilitate materials exchange and distribution, environmental monitoring and prediction of demand. These capabilities have immense potential to improve the efficiency and success of UH, where overall production is the result of many individual growers and organizations working at small scales. Benefits may range from optimizing crop choices for an allotment site to reducing waste by accurate just-in-time production coupled with data-driven predictions of demand.

The greatest challenges are the social and cultural factors that can drive or constrain UH. This includes the potential competition between UH and other uses of green infrastructure. A better understanding of the co-benefits of growing space (in terms of other ecosystem services, for example) may help to reduce these tensions. Extensive adoption of UH in private spaces cannot be readily legislated for, and relies on encouraging cultural and social changes ranging from a response to perceived national need (as for example during the United Kingdom's 'Dig for Victory' campaign in the Second World War) to personal health and well-being benefits.

Moving beyond theory into the city

Cities, as population centres, are now exerting their power to influence the conventional global food system towards one that operates in a more sustainable and equitable way[36]. For example, 209 cities globally are now signatories of the Milan Urban Food Policy Pact[37], which commits them "to develop sustainable food systems that are inclusive, resilient, safe and diverse…" and recommends actions to "promote and strengthen urban and peri-urban food production". Indeed, many cities have developed urban food strategies to try to enact these changes[36], including our case study city (although Sheffield is not a signatory to the Milan Urban Food Policy Pact).

Sheffield has developed a Food and Wellbeing Strategy[38], recognizing the interconnectedness of food and public health. The generic framework for expansion of the UH system presented in Fig. 2, and exemplified by the potential areas for UH identified in Sheffield (Fig. 1), provides a model for expanding UH to achieve goals set out in the urban food strategies of other cities of the Global North (For example, London and Bristol in the United Kingdom, Toronto and Vancouver in Canada and Chicago and Los Angeles in the United States[36]).

A theme common to many of these strategies and the Milan Urban Food Policy Pact is an increase in local food production, and in Sheffield there is the recognition that the council should support the expansion of UH into council-owned green infrastructure (which would include areas identified in our GIS analyses[38]). The Sheffield Food and Wellbeing Strategy also recognizes the role of the local authority in procurement and provision of food within its municipal buildings (such as hospitals, schools and leisure centres). Albeit not explicit in their strategy, there is clear potential for the council to act as an 'anchor institution' to provide security to new UH community-based businesses (Fig. 2). There is also a recognition that council buildings could be used to distribute food or act as retail spaces for social supermarkets alongside the potential to use these spaces (or at least their rooftops) for CEH.

Developments in technology (such as enabling knowledge sharing, improving the sustainability of growing practices and produce distribution networks; see Fig. 2) will underpin the delivery of an expanding UH system. These advances will essentially enable the creation of 'smart food cities' that promote diverse food production practices within urban areas, and also the social innovations necessary to drive their delivery[39]. However, realizing the potential for enhanced food production from UH is a multifaceted challenge. It is not all about social change, nor all about technological fixes — both have a role to play. For UH production to expand sustainably, a more widespread understanding of its potential amongst urban planners, policymakers and businesses must be fostered. Such understanding may be enhanced by the use of demonstrator SBH and CEH systems. While our conceptual model highlights the diverse forms of UH that may be effective in urban systems, this understanding must also draw on frameworks that emphasize the spatial integration of food production, such as the Continuous Productive Urban Landscapes concept[40]. Public engagement is also critical, detailed local insight and mapping of opportunities can enable people to envision their environment differently (for example, the Edible Map Project; http://mikeytomkins.co.uk/category/maps). It will require sustained effort to achieve this potential, but delivering more of it could significantly improve urban food security, alongside other ecosystem service benefits in urban areas.

Data availability

The datasets generated from GIS analyses using OS Mastermap for areas of green space and flat roofs potentially suitable for urban horticulture identified in Sheffield are available via Mendeley Data (https://doi.org/10.17632/2fscg3m53d.1).

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Author contributions

All authors wrote the manuscript. N.M., D.R.G. and J.L.E. designed the spatial analyses. J.L.E. and J.R.L. designed the SBH research. M.C.D., P.H.W. and J.L.E.

investigated the labour involved in allotment-based urban horticulture. D.D.C., G.K.P. and A.J.R. researched CEH foams. V.S. advised on water use. D.O.D.T. provided expertise on building structure. H.C., D.D.C., A.J.R., J.L.E., N.T.B. and J.N. researched CEH.

Competing interests
The authors declare no competing interests.

Additional information
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