Potential of urban green spaces for supporting horticultural production: a national scale analysis

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Abstract

As urban areas and land-use constraints grow, there is increasing interest in utilizing urban spaces for food production. Several studies have uncovered significant potential for urban growing to supplement production of fruit and vegetables, focusing on one or two cities as case studies, whilst others have assessed the global scale potential.

Here, we provide a national-scale analysis of the horticultural production potential of urban green spaces, which is a relevant scale for agri-food and urban development policy making using Great Britain (GB) as a case study.

Urban green spaces available for horticultural production across GB are identified and potential yields quantified based on three production options. The distribution of urban green spaces within 26 urban towns and cities across GB are then examined to understand the productive potential compared to their total extent and populations.

Urban green spaces in GB, at their upper limit, have the capacity to support production that is 8x greater than current domestic production of fruit and vegetables. This amounts to 38% of current domestic production and imports combined, or >400% if exotic fruits and vegetables less suited to GB growing conditions are excluded. Most urban green spaces nationally are found to fall within a small number of categories, with private residential gardens and amenity spaces making up the majority of space. By examining towns and cities across GB in further detail, we find that the area of green space does not vary greatly between urban conurbations of different sizes, and all are found to have substantial potential to meet the dietary needs of the local urban population. This study highlights that national policies can be suitably developed to support urban agriculture and that making use of urban green spaces for food production could help to enhance the resilience of the national-scale food system to shocks in import pathways, or disruptions to domestic production and distribution.

Keywords: Resilience, Food sovereignty, urban agriculture, Green spaces, Horticultural production potential, Towns and cities

1 Introduction

Meeting the dietary needs of growing urban populations in a sustainable manner presents a significant challenge, particularly under the limitations of decreasing land availability due to climate change and land degradation, and a need to preserve natural resources and protect biodiversity. Urbanization can also drive land use change and contribute to the reduction in available land for agriculture (Satterthwaite et al., 2010, Barthel et al., 2019). Global projections indicate that by 2100 residential and commercial demand for urban land could range from approximately 1.1 million to 3.6 million km^2 (Gao and O'Neill, 2020). Urban dwellers are expected to form 67% of the global population by 2050 (UN Department of Economic and Social Affairs, 2018), and new urban land will need to be designated to support this trend (Gao and O'Neill, 2020). These population and land use trends are driving increasing global interest in incorporating food production into the urban landscape. For example, the intergovernmental panel on climate change highlights the role of urban agriculture (UA) in climate mitigation (IPCC, 2018), the Food and Agriculture Organization encourages integrating urban food into urban planning (Cabannes, 2018, FAO, 2021), and there is increasing recognition that small-scale food production in urban areas contributes to the sustainable development goals (Nicholls et al., 2020). Urban agriculture (UA) refers to the production of food in urban and suburban environments (Orsini et al., 2013, Orsini et al., 2020). Here we focus on urban horticulture specifically the production of fruit and vegetables.

Another major driver of urbanization is the need for food sovereignty, defined as locally held control over all aspects of the food system, including food markets, natural resources, food cultures and methods of food production (Wittman, 2011, Lang and Barling, 2012).This has become particularly apparent with the current COVID-19 crisis as interest in national self-sufficiency is growing (Garnett et al., 2020) as a way to overcome supply chain disruptions. The United Kingdom's (UK) food supply is particularly vulnerable to food system shocks like COVID-19 and Brexit (Lang et al., 2018, Lang and McKee, 2018), as a net importer of food, with a high reliance on imported fruit and vegetables, including from drought prone countries (Hess et al., 2016, Hess and Sutcliffe, 2018) to meet a national demand deficit (de Ruiter et al., 2016). Even more concerning: between 1996 and 2015 fresh fruit and vegetable (FF&V) imports into the UK almost doubled as shown in data from the Department of Agriculture, Food and Rural Affairs (DEFRA), and this reliance on imported food (which removes oversight in food supply), combined with unprecedented political changes and global health challenges in the UK (which disrupt supplies of imported food and hinder the flow of horticulture workers, relied upon for the production of local food in GB), place the national food system at risk in terms of food access and availability. This risk is highlighted by the recent National Food

Strategy (Dimbleby, 2021). Poor food access and availability are recognized forms of food insecurity (Leroy et al., 2015, Larson et al., 2020).

A number of recent studies have indicated that the productive potential of urban areas is large and meaningful when compared to food needs. In a global scale analysis, estimates suggest that 25-50% of the UK's urban space could be cultivated to meet the daily recommended intake of FF&V for urban dwellers (Martellozzo et al., 2014). Another study showed that 5-10% of the global production of pulses, roots, tubers, and vegetables could be supported by urban growing (Clinton et al., 2018). A more geographically focused analysis of allotment areas in Sheffield, a large UK city, found that there is more than enough land in Sheffield to support all the FF&V needs of its inhabitants. In their estimates, Sheffield has the potential to support four times the production of commercial horticulture, with significant potential to shorten supply chains and improve food access (Edmondson et al., 2019, Edmondson et al., 2020a). Analysis of another UK city, Leicester, showed that allotment growing is as productive as commercial growing, and just 1.5% of land area there has the potential to produce FF&V for 2.6% of its population (Edmondson et al., 2020a, Grafius et al., 2020). These studies showed that urban agriculture can potentially supplement conventional production and food supply, and that it has a role to play in food systems resilience. However, urban agriculture potential at the national scale has yet to be addressed. This is an important knowledge gap to fill since many of the policies that enable or hinder urban food growing are made at a national level, and this scale is of most relevance within an imports and food system resilience context.

Food system resilience is the active capacity to continue to achieve goals around food security despite disturbances and shocks (Tendall et al., 2015). These shocks may be economic in the form of increasing land prices, or environmental such as floods and droughts (Misselhorn et al., 2012). Resilience entails building robustness (the ability to withstand disruption), recovery (the ability to quickly 'bounce back') and adaptation (the potential to re-organize) in the system (Ingram, 2017). In this context there is a role for diversifying food import supply chains to withstand sudden supply shocks (Marchand et al., 2016) as a way of contributing to robustness (Kummu et al., 2020), so long as there is not an over-dependence on imported food, which would have the opposite effect in increasing food system vulnerability (Kummu et al., 2020). There are also clear contributions from urban agriculture to 'adaption' in changing farm systems, diversifying food sources and increasing the number of operators (Ingram, 2017), to deliver food locally and in a sustained way (Grafton et al., 2015). Although there are challenges to overcome in urban food production i.e. food safety issues, land access and regulatory barriers (Lovell, 2010, Castillo et al., 2013).

To understand the role that urban agricultural expansion could play in national food sovereignty and resilience, we need a national-scale approach. Whilst local authorities often have significant influence over use of local land resources, many policies critical for the development of UA are made at a national level, including those relating to agricultural production and national food security, the provision of housing, education and priorities for delivering economic development, yet UA is almost absent from this policy scale (Lovell, 2010, Fox-Kämper et al., 2018, Orsini et al., 2020). In this study, we evaluated the horticultural productive potential of urban green spaces across Great Britain and compared this potential to current conventional domestic production and imports to provide an insight into the relevance of urban agriculture for increasing national food self-sufficiency. We also disaggregated this analysis into urban green space categories, and examined a range of towns and cities of varying scales in order to provide insights into where changes to policy and practice could provide the most impact.

2 Methods

2.1 Great Britain as a national scale case study

Britain constitutes an interesting national scale case study for this analysis because of its densely populated nature and low self-sufficiency for FF&V, as discussed in the introduction. As a net importer of food it is highly reliant on agricultural imports from the European Union. The UK's self-sufficiency ratio is 61% for all food and 75% for indigenous food (i.e. foods that are traditionally part of UK diets, and are currently or in the past, produced locally). A range of foods are also exported from the UK including high-value, processed products through to low-value products that fail to find a market. The main export markets are Ireland, the United States and France (National Farmers' Union of England and Wales, 2017). Current projections also indicate relatively high rates of urban population growth, with 90% of the UK's population projected to live in urban areas in 2050, in comparison to the European average of 83% (UN Department of Economic and Social Affairs, 2018). This exposes the UK food system to risk of labor shortages in rural locations where agriculture is traditionally located, as well as transport and supply chain disruptions, which would have the negative effect of increasing the price of food or leading to shortages of FF&V.

2.2 Estimation of urban green spaces available for horticultural production

The urban environment can offer a diverse set of spaces for the expansion of urban growing, including outdoor green spaces, brownfield sites, rooftops and facades, as well as indoor and underground spaces. Here, we focused on the horticultural potential of outdoor green spaces as they have relatively low set-up/retro-fitting costs (barring certain unique crops like apple orchards), especially when compared to vertical systems (Eaves and Eaves, 2018); are comparatively easy to access; and can support a diverse range of crops relatively cheaply, without the capital and operating expenses associated with growing substrate, indoor infrastructure and energy accompanying indoor growing (Benke and Tomkins, 2017, Eaves and Eaves, 2018). Furthermore, green spaces currently support, to some degree, the growing of amenity (non-edible) plants, trees and crops. Suitability of outdoor green spaces can also be improved through site additions, such as soil conditioning, raised beds, or polytunnel and glass house construction, the latter being useful for seedling production or year round growing. However, we acknowledge the potential of non-green space growing options, and the inclusion of these would likely increase the horticultural productive potential estimate here substantially, particularly for leafy green vegetables, soft fruit and tomato crops that are well suited to indoor/rooftop environments.

In an effort to critically review how green spaces are understood in the context of food and plant production and which spaces are regarded as 'usable green space'; we note that Kabisch and Haase (2013) broadly regard green spaces as any vegetation found in the urban environment, which include parks, open spaces, residential gardens, or street trees. They also recognize the potential to create green spaces in 'non-green spaces' through demolition of building and artificial structures, de-sealing of soils and re-use of brownfield sites. Daniels et al. (2018) recognize that green spaces may differ in their extent of natural and artificial elements, and therefore their benefits from a multidimensional perspective should be considered cautiously. In their analysis Tyrväinen et al. (2007) showed that green space classifications are strongly influenced by social perceptions. A comprehensive review (Rupprecht et al., 2015) showed that certain green spaces (e.g. naturally vegetated spaces or highly managed spaces), although receiving more attention were not the only types of green spaces. They found an absence of a formal definition of green spaces and instead a myriad of typologies or 'hybrid states' to categorize green spaces that can be based on land tenure, conservation, maintenance regimes, use, regulation, and legitimacy. This is thought to make the definition of green spaces overwrought with uncertainty (McLain et al., 2014).

In our analysis we used a data set at the scale of Great Britain (England, Wales and Scotland) that encompassed green spaces with both artificial and natural elements (see: https://www.ordnancesurvey.co.uk/xml/codelists/OpenFunctionValue.xml). We considered all green spaces as potentially suitable spaces for urban agriculture, unless they were water bodies, foreshores or beaches. This was regarded on the basis that artificial elements could be removed, surfaces unsealed, buildings demolished or brownfield sites reclaimed (Kabisch and Haase, 2013). This OS Master Map Green space product (Ordnance Survey, 2017) was used to delineate urban green spaces across the UK. The areal limits of this dataset only extend to the countries of Great Britain, thus we constrained our analysis to these countries. This dataset categorizes the natural environment in major urban areas across both public and private spaces and uses the British National Grid (BNG) spatial reference system to describe the easting and northing coordinates of urban green spaces in units of meters. The Master Map Green space Layer is made up of a subset of the Topographic Area polygons from OSMM Topography Layer identified by a unique identifier (TOID). Each polygon (land parcel) has been assigned a primary function and form and, in certain cases, secondary functions and forms. This initial dataset, imported into ArcGIS Pro comprised 33,354,035 rows of data across several attribute tables. After filtering to remove water bodies (inland water, foreshores and beaches) seen as spaces unsuitable for urban growing, the data was exported as .csv files and merged into a MySQL database for data cleaning. Duplicates were searched by generating data queries against the unique TOID to remove identical rows of data and a final dataset for analysis was produced (see load-log provided as supplementary data).

In the final dataset, 18 categories remained of green space suitable for outdoor urban horticulture from the OS data, based on their primary function categorization (Figure 1).

2.3 Quantification of potential urban horticultural production

Selecting crops for urban agriculture is influenced by a wide range of factors including considerations of land and soil suitability, requirements in terms of crop inputs and labor (McDougall et al., 2019, Edmondson et al., 2019, Lal, 2020). In this study, we used current domestic horticultural production as a representative guide to the crops that are both relatively suited to the biophysical growing conditions of GB and the food preferences of its residents. Hence, to produce a shortlist of crops for inclusion we analyzed data from UK Horticulture statistics from DEFRA (2019). This yielded six main FF&V categories: (i) orchard fruit, (ii) soft fruit, (iii) roots and onions, (iv) brassicas, (v) legumes, and (vi) others (including peppers and salad greens), which we included in our analysis (Table 1). We acknowledge that certain soil and climate factors can make areas more suited to particular crop categories. However, in urban settings, conditions can be more easily manipulated through the use of physical barriers against wind, hail and pest damage or the use of rain water harvesting in water supply; hence, we maintain this simple assumption that these would be the main crop types produced.

<INSERT TABLE 1 ABOUT HERE>

We explored three options (Table 2) for the allocation of growing space to the six crop categories: a) an equal split where each polygon was divided equally between the six FF&V categories described above (Total production per land allocation was described as the “Equal-

Split option"); b) a split proportionate to domestic production, where each polygon was divided to match the area of land currently under commercial FF&V production in the UK, as reported by DEFRA (2019) (breakdown by crop category was described as the "Domestic-Production option"), and c) a split based on economic value where each polygon was divided according to the crop value of each crop category in the DEFRA (2019) dataset. Scenario a), then, represents the baseline option, scenario b) assumes that UA crops would be shaped by similar market, policy and biophysical conditions that conventional horticulture growers experience, and c) assumes that high value crops are more desirable as they can be sold at a premium price so more are grown, but all crops are still included for diversity of production (breakdown by economic value was described as the "Price-Value option").

<INSERT TABLE 2 ABOUT HERE>

We assumed production in these areas would be equivalent to the national domestic average as indicated by the DEFRA statistics to estimate the yield per area for outdoor urban green spaces. Using data from a 20-year period (1996-2015), we summarized the yields for the six crop categories per unit area of land (Table 1). We averaged this over 20 years to remove year-on-year variability, after first examining the data trends to ensure there were no substantial systematic changes in productivity over the 20-year period. Likewise, we tabulated the average value for each of these crops, per unit area.

2.4 Estimating the relevance of urban horticultural production to national FF&V self-sufficiency

In order to estimate the relevance of potential urban horticulture to national scale food system resilience, we compared the yield estimates as described in 2.3 to the quantity of food imported into the GB. In line with our production estimate methodology, we used DEFRA's 2019 horticulture data on imports for the same time period (2006-2015) and organized these data into the same six broad crop categories described above. Where there were FF&V categories that did not correspond to the six domestic crop categories (e.g., avocados, bananas, grapes, and sweet potatoes) we included these into exotic fruit and exotic vegetable categories. They represented imports that were not suitable for GB production at scale, but are nonetheless important contributors to overall supply of FF&V.

Next, to understand how much food could be produced if all green spaces were substituted for urban agriculture, the total horticultural productive potential under three options for sub-allocation of crops (Table 2) in urban green spaces were calculated, as described in section 2.3.

2.5 City-scale comparison of horticultural productive potential

To examine the distribution of urban green spaces within small, medium and large urban towns and cities across GB and understand the productive potential compared to their total extent and populations, green spaces were extracted within the boundaries of major cities, towns and settlements in England, Wales and Scotland at 26 locations. These represented different climate and socio-economic areas of GB, and excluded London which was regarded to be an anomaly due to its population size. We summarized the green spaces and horticultural productive potential within the boundaries of these GB towns, and compared these to population sizes for these settlements (Office National Statistics, 2019), in order to explore the degree to which urban areas have differing green space characteristics and urban horticultural production potential. To generate a figure of yield potential under the “Equal-Split” option, we divided total yield across the green spaces by population size, providing an estimate of yield per person in kilograms.

The boundaries for England and Wales were defined using the Major Towns and Cities dataset from the Office of National Statistics, and the Settlements shape file from the National Records (NRS) was used for Scotland (Table 3). Towns and cities were categorized into small, medium and large cities and shown in Figure 3 based on their population and area size.

<INSERT TABLE 3 ABOUT HERE>

3 Results

3.1 Urban green spaces available for horticultural production

Figure 1 provides a breakdown of the types of urban green space in GB, showing the total number of land parcels along with mean parcel sizes. These data highlight that more than half of these urban green spaces were contained in just two categories: private gardens (34%) and amenity areas for residential or business purposes (23%) (percentages in Figure 1a). Allotments or community gardens, that are currently managed as productive spaces for urban agriculture within the urban framework of towns and cities, make up about 1% of urban green space nationally.

The data also highlighted that whilst private gardens made up the largest total area, this area comprised many relatively small spaces (Figure 1b). Recreational spaces and parks tended to have much greater mean areas per land parcel, and in total, they contributed to a moderate proportion (>10%) of the total GB green space.

<INSERT FIGURE 1 ABOUT HERE>

3.2 Potential production of FF&V in urban green spaces at GB scale compared with conventional domestic production and imports

A similar total tonnage of FF&V is produced under all three crop-allocation options, but with differences in the production for each category of FF&V (Table 2). At its upper limit, we estimated that urban green space could support production of 20.70 –22.41 metric tons (MT) of FF&V per year in GB, if all urban green spaces were utilized and expected average crop yields were achieved. This compared with total average annual domestic production of 2.89 MT and imports of 56.40 MT. Hence, the estimates for potential urban production equated to 35–38% of total domestic production and imports. Comparing only the categories of FF&V that are suitable for production in GB (i.e., excluding exotic FF&V categories), then our estimates indicated that urban green space could produce between 3.8–4.1x the total FF&V produced domestically (Table 2). Examining the production estimates on a crop category basis (Figure 2b), the total production potential for each crop sub-allocation option exceeded imports and domestic production, apart from exotic FF&V categories, which are purposefully excluded from the urban production estimates. Results of this analysis are presented in Figure 2.

<INSERT FIGURE 2 ABOUT HERE>

3.3 Variation in green space and in horticulture productive potential per capita between cities across GB

We found that total productive green space area as a proportion of the total urban land area varied between 43–57% across the selected locations (Table 4). By including the population data of towns and cities, and quantifying the amount of food that could be produced under the "Equal-Split Option" we estimated productivity per person varied between 171–281 kg per annum across towns and cities (Table 4). When this is compared to the recommended daily intake of fresh fruit and vegetables, recommended by the WHO and FAO (400g/day or 146kg/y), we determine that if all green space was committed to urban growing, local residents could produce more than enough FF&V to meet their personal dietary requirement.

<INSERT TABLE 4 ABOUT HERE>

In our subset of 26 GB towns and cities (Figure 3), we found that private gardens, which are the most abundant green space category, vary as a percentage of productive green space between 41–69% of green space, with the Scottish towns and cities (Aberdeen, Edinburgh and Stirling) tending to have less space attributed to private gardens. In this subset of GB towns and cities; amenity and residential areas make up between 8–22% of green spaces and allotments and community gardens make up between 0–2.6% of green space, and this looks slightly different to the national picture.

<INSERT FIGURE 3 ABOUT HERE>

4 Discussion

This study presents the first national level assessment of horticulture productive potential in urban green spaces, providing evidence that may support the adoption of urban horticulture as a tool to increasing national food self-sufficiency, which may in turn build system resilience and food sovereignty. One way urban food growing contributes to food system resilience (Olsson et al., 2016) is by enhancing food production as part of multifaceted urban land use, and this in-turn re-couples agriculture to the regional food system. This can happen through incentives and spatial planning to access urban land, provision of local food markets, and networks to link supply chain actors. There are however challenges relating to production inefficiencies, labor and resource use (McDougall et al., 2019). These will need to be addressed in ensuring UA becomes a viable diversification option for food production. For example, social sustainability tends to be low due to the seasonal, temporary nature of agricultural work (Mitaritonna and Ragot, 2020) which may lead to poor rights and participation of workers (Molinero-Gerbeau et al., 2021). There are also food safety risks from pesticides and heavy metal pollutants in urban environments (Mok et al., 2014, McDougall et al., 2019).

This national scale case study addresses a current research and policy gap (Fox-Kämper et al., 2018, Orsini et al., 2020) by carrying out an analysis relevant to the scale of national policy making. This is timely, as the UK's food system has come under pressure from political, health and labor issues in recent times (Schramski et al., 2019, Garnett et al., 2020), motivating governments and society to reconsider where and how food is produced in the UK. While issues around food insecurity and disruptions to food supply are heightened in the UK by reliance on imports, urbanization, COVID-19, and Brexit, the UK is not an exclusive case. Some studies have shown increasing concern for disruptions to national food supply chains and knock on impacts to food production cycles (e.g. Brazil, the Middle East) and price volatility (e.g. South Africa), and even household food insecurity (e.g. China) (Pu and Zhong, 2020, Devereux et al., 2020) .

The spatial analysis of urban green spaces at the national level revealed that over half of green spaces in urban areas are made up of private gardens and privately-held land used for amenity gardens, with only a small fraction ~1% of green space currently being used formally for food growing (i.e., allotments and community gardens). This finding suggests that if expansion of urban agriculture was to be implemented as a national priority, instruments that promote and enable food growing in private spaces and households would be important to consider. Although this would need to take heed of the organizational differences of UA in terms of beneficiaries, distribution channels and actors (i.e. self-growing / socio-cultural / commercial) (Krikser et al., 2016). This could constitute the provision of incentives to incorporate sufficient growing space into new residential developments, offering tax rebates or growing subsidies to property owners who engage in, or allow the use of, urban land parcels for urban growing, as well as education schemes, advice networks, and campaigns targeting urban growers specifically (e.g., an extension of 'Dig for Britain', 'Pick for Britain' or 'Clap for the NHS'). The latter would also address the risk of agricultural supply disruptions due to labor shortages across rural and urban locations. However, incentivizing production in private spaces may exacerbate social inequities, as this is an opportunity only available to those with space. If public money is used, the mechanisms by which food produced privately could produce public goods would be important to consider.

However, a case could also be made that publicly held green spaces, such as parks, might be attractive options to local authorities for supporting urban food growing activities given that these spaces are more likely to be in their direct control. Consistent declines in funding due to austerity measures has significantly decreased national budget allocations to local councils across Britain, impacting their budget to manage green space, and this has already encouraged individuals and communities to take on an increased responsibility for local services (Whitten, 2019). Furthermore, the larger land parcel sizes of parks mean that they may provide more space to accommodate growing projects at scale (particularly for social or commercial enterprises), with less likelihood of light shading drawbacks and a better concentration of resources (e.g., skilled labor or transport), which may pose a challenge where sites are smaller and more dispersed in a city.

Our analysis suggests that urban green space at the GB level has the capacity to support production of nationally significant volumes of FF&V, helping to re-orient food systems to produce more food locally, increase food sovereignty and support food system resilience. These estimates of horticulture productive potential should be considered as being near to the extreme upper limit for production in GB urban green spaces where all space is utilized well, growers have sufficient skills, knowledge and resources to support effective production, and growing conditions are suitable (e.g. climate, soil, light, etc.). In reality, realizing this productive potential is contingent on uptake of urban growing by local stakeholders, ease of access to green spaces and resource supports in the form of finance, knowledge and institutional capital (Schupp et al., 2016, Mead et al., 2021b). Nonetheless, our results indicate that further consideration of urban green spaces as potential contributors to meaningful levels of FF&V

supply at a national scale are warranted. For example, even if only a small percentage of this area is agronomically suitable and available, this could still represent a substantial contribution to national supplies of FF&V.

This national scale assessment also allowed for an estimate of current levels of urban FF&V production in spaces devoted to food growing. We estimated that the space dedicated to allotments and community growing across GB may currently support production of FF&V equivalent to ~0.01% of domestic commercial production. Urban production of FF&V is likely to be higher than this figure as this neglects growing undertaken in private residential settings, institutional grounds, and other settings. Other smaller scale studies have shown that 1.5% of allotment land can support 3% of the fresh food needs of an urban population (Edmondson et al., 2020b).

We also analyzed and mapped the food production potential across small, medium, and large cities to provide a better understanding of how productive potential might vary across urban centers nationally, and how potential might compare to the size of local populations where locally grown FF&V is more likely to be consumed (Figure 3, Table 4). We found that total green space area as a proportion of urban extent varied by 12% across the locations selected, and this variation did not appear to be systematically related to town or city size (in terms of land area footprint) (Table 4). This is in contrast to the findings of Martellozzo et al. (2014) in their global scale analysis that suggested smaller towns, which are more abundant, would have greater potential for urban growing.

Whilst productive potential varied across the urban conurbations studied here, they were all relatively high compared to the dietary needs of the local population. Productivity per person could be as high as 281 kg per annum which is a substantial volume of food per person in dietary terms. By comparison, the Food and Agriculture Organization (FAO) and World Health Organization (WHO) recommend adults consume a minimum of 400 g of fruit and vegetables per day (FAO and WHO, 2019), equating to 146 kg per year. By our calculation, productivity per person could be as high as 1.9 x the recommended yearly fruits and vegetables consumption per person per year (at 281 kg). The estimated upper limit for FF&V production per person in all the locations studied was in excess of this annual recommendation. From a national governance perspective, the town/city scale analysis presented here suggests that policies and mechanisms for incentivizing FF&V growing are likely to be valuable across small, medium and large cities alike and national level approaches could be suitable in the GB context.

In addition to national scale resilience of FF&V supply, increasing urban agriculture may confer additional benefits, directly through the provision of ecosystem services (e.g., climate regulation, sequestration benefits), and indirectly by improving well-being, through diet quality and connection to nature (Clinton et al., 2018, Kingsley et al., 2021, Mead et al., 2021a, Evans et al., under review). Furthermore, because the scale of production in urban agriculture is often small, FF&V tend to be sold or consumed locally, and this contributes to local food production and resilience, replacing purchases of imported food. This is known as import substitution (Rodrigues, 2010, Ershova and Ershov, 2016). Although import substitution, as a development theory, promotes productivity and economic gains at a national level, Bellows and Hamm (2001) showed that import substitution can promote local autonomy and sustainable development at a localized food system level, and this proximity to urban agriculture may in-turn encourage positive dietary behaviors in local people (Mead et al., 2021a).

4.1 Limitations

This analysis made assumptions in order provide a simple, nation-wide basis for estimation of yields. However, we acknowledge that there are limitations to the approach as yields will rely on climatic factors, nutrient availability, soil type, access to light, pest and disease pressure and grower skill levels which have not been considered in our analysis. From this perspective, our analysis of horticulture productive potential may be considered an upper-estimate.

Our predictions also assumed that urban growers are capable of achieving the same yields as conventional growers. This is could be viewed as a limitation, however, this assumption aligns with studies showing that urban horticultural production systems may yield higher than commercial field settings (Edmondson et al., 2020a, McDougall et al., 2019, Kingsley et al., 2021), due in part to land management approaches which enhance ecosystem service provisions and improve soil quality (Edmondson et al., 2014). Urban horticultural production environments such as allotments may have a greater input of manual labor hours which when combined with complementary cropping can facilitate “over-yielding” (McDougall et al., 2019). Yet alternative evidence (Cook et al., 2012) suggests that yields may be lower in allotment settings with a greater diversity of crops.

As the study focuses on yield as a measure of productive potential, we also do not consider the infrastructure requirements post-production. For example, storage and processing facilities would be needed to accommodate increased production, and would help avoid post-harvest loss and improve availability throughout the year.

In a food production context Krikser et al. (2016) highlight that there may be different typologies of UA related to form and function, and their characteristics of space, market orientation, financing, products and activities. They identify these dimensions of UA as self-supply, socio-cultural or commercial. We do not attempt to address horticultural production at this level of complexity, as it appears more suited to analysis at a more local (e.g. city) scale.

5 Conclusion

This study provided the first national scale analysis of the role that expanding urban agriculture in green spaces could play in increasing both the production of fresh fruit and vegetables, and national food system resilience and sovereignty. We found that urban green spaces are substantially underutilized for urban food production, with opportunities for coordinated campaigns and financial incentives to stimulate the productive utilization of urban land as a resource for food production. The presence of publicly held land within the urban green space network in the form of amenity gardens managed by local councils could play a crucial role in building knowledge and social capacity for urban agriculture. With allotments and community gardens already supporting a network of committed and knowledgeable gardeners, a rich source of knowledge and skills is already present in urban areas which can be leveraged to provide technical support to other members of the public, as a way of encouraging engagement in urban growing. The relative homogeneity of urban green spaces across towns and cities of different land and population size, suggests that urban agriculture potential is independent of demographic and economic factors, and that if only a proportion of the population engage in urban agriculture, the productive output in terms of meeting healthy dietary guidelines could be significant. This provides another avenue for national policy makers to achieve efforts to tackle diseases like obesity, diabetes, and heart disease, while addressing systemic issues like household food poverty in the process. This evidence suggested that as well as an environmental incentive to the uptake of urban growing, there may be an economic and social motivation for supporting urban agriculture.

Data access statement

The data used in this analysis is based on publicly available data sources. Supplementary information has been included with this manuscript.

Ethics statement

No human or animal subjects were used in this research and ethical approval was not required.

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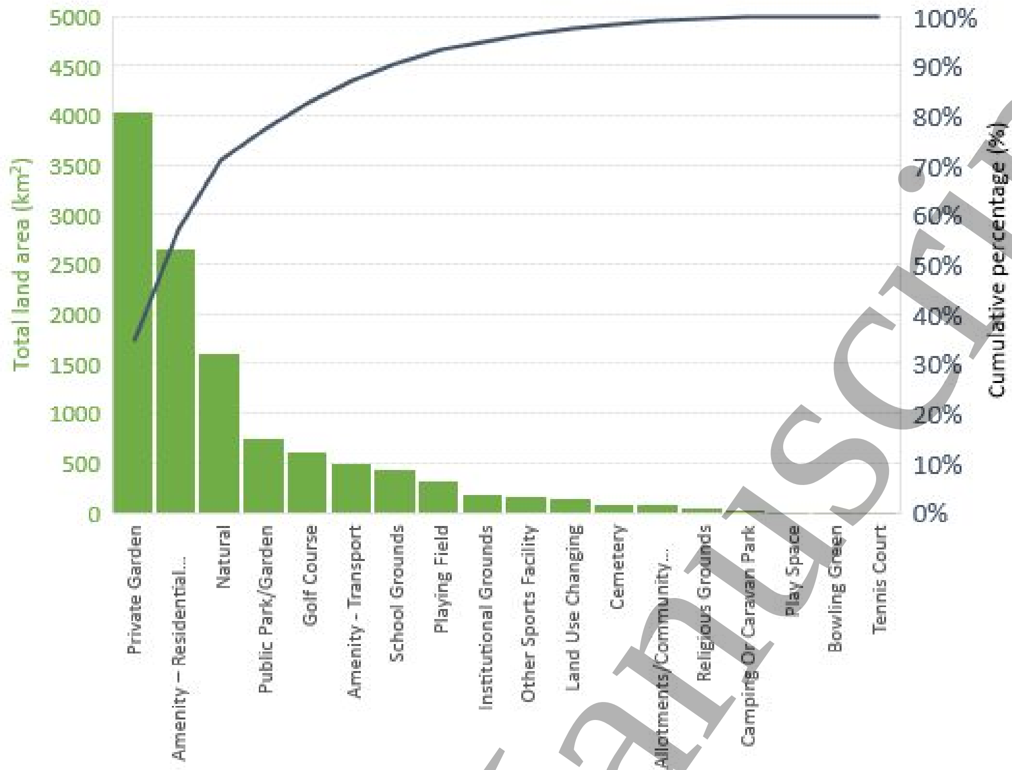
a)



b)

Figure 1: Characteristics of green space in Great Britain. a) Comparison of the green spaces in GB by total area and as a cumulative percentage of the total green space area (in km²)across England, Wales and Scotland. b) Total number of land parcels in each category and their mean area (in m²).

a)

b)

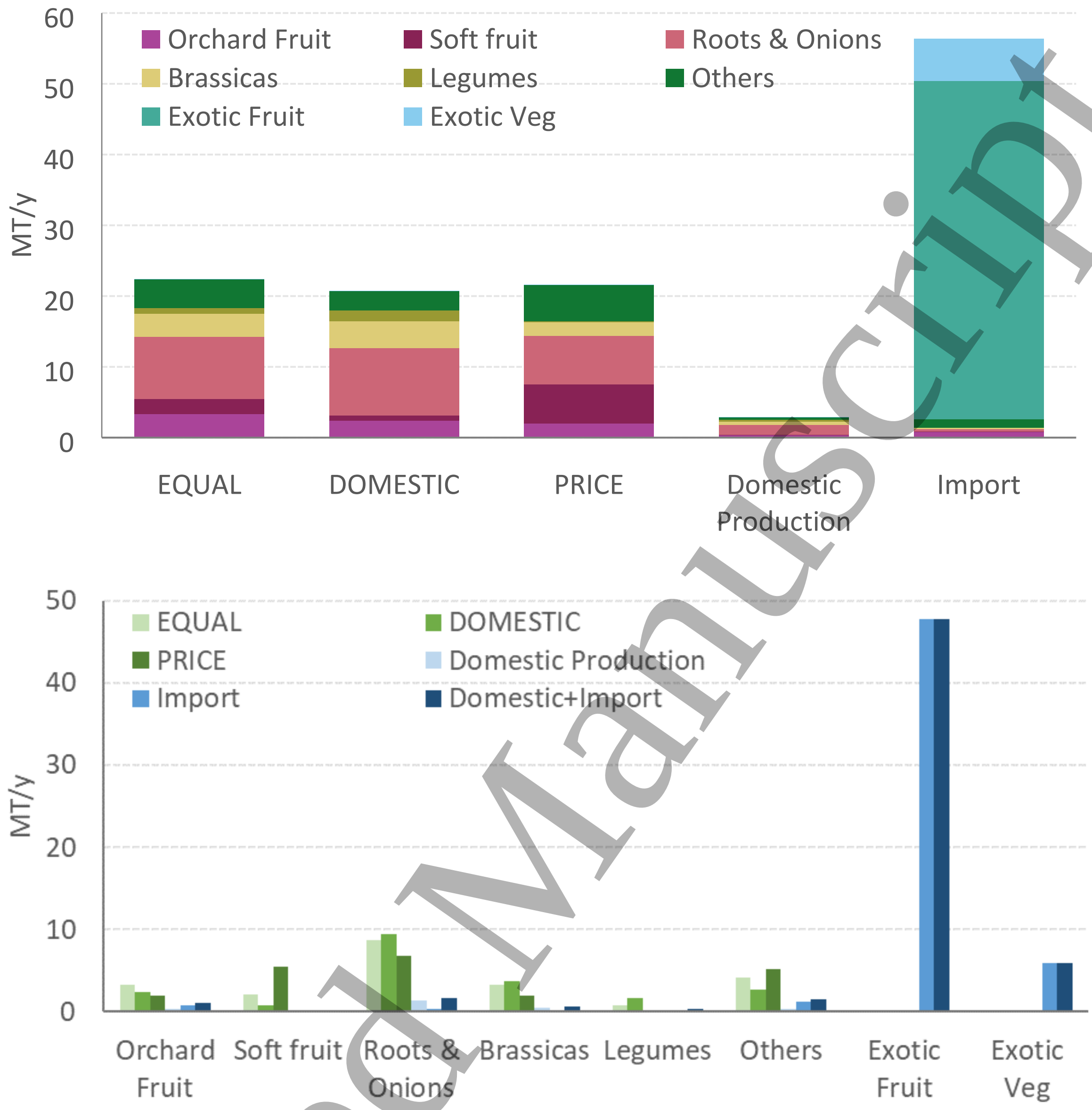


Figure 2: Estimated national production potential of fresh fruit and vegetables expressed as metric tons per year (MT/y) for GB green spaces compared with domestic production and imports. Section 2.3 further described that estimates were based on 3 options. a) Total production per land allocation: Equal-Split option. b) Breakdown by crop category: Domestic-Production option. c) Breakdown by economic value: Price- option

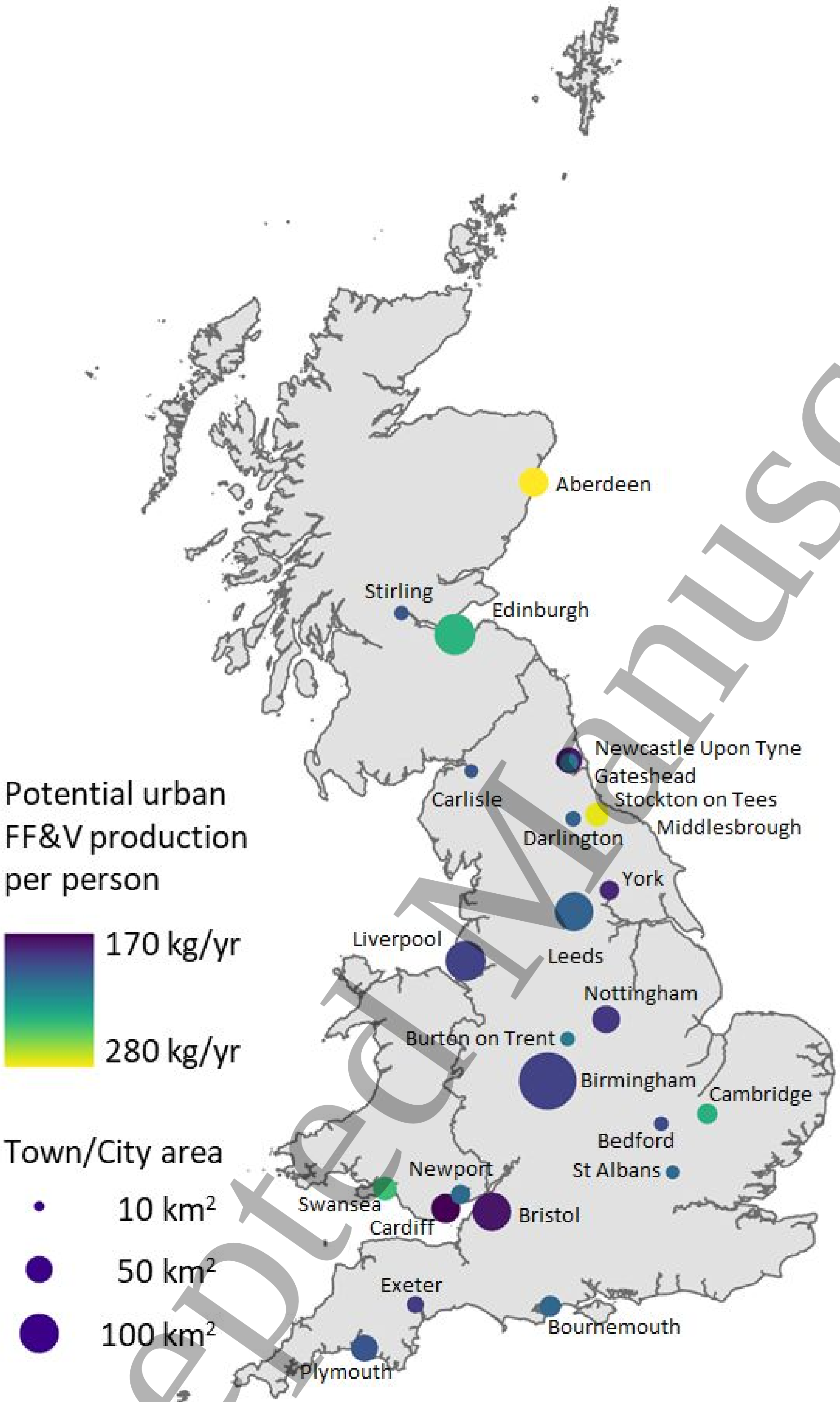


Figure 3. The location of 26 Great Britain towns and cities analysed for their urban fresh fruit and vegetables (FF&V) production expressed as kg per year (kg/y) in relation to town and city size.

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Table 1: Categories of Fresh Fruit and Vegetables (FF&V) produced in the UK classified in line with DEFRA horticulture categories (DEFRA, 2019), calculated as 20-year average output in tons per hectare (T/ha), area devoted to production (ha) and value (£ /ha).

FF&V categories (Total)	Mean domestic production, T/ha	Area, ha	Area as a % of total	Value, £ Million/ha
Orchard Fruit	17	19,983	12%	0.0066
Soft fruit	11	8,954	6%	0.0279
Roots & Onions	45	29,648	18%	0.0086
Brassicas	17	29,879	19%	0.0065
Legumes	4	55,125	34%	0.0014
Others	21	17,026	11%	0.0135

Table 2: Fresh fruit and vegetable (FF&V) production in metric tonnes per year (MT/y) under different production options and 20 year average domestic production and imports.

	Urban greenspace production potential (MT/y)			Domestic Production (MT/y)	Import (MT/y)	Domestic + Imports (MT/y)
FF&V Categories	EQUAL	DOMESTIC	PRICE			
Orchard Fruit	3.313	2.385	1.988	0.341	0.791	1.132
Soft fruit	2.144	0.772	5.531	0.102	0.061	0.163
Roots & Onions	8.770	9.471	6.841	1.334	0.356	1.690
Brassicas	3.313	3.777	1.988	0.508	0.172	0.680
Legumes	0.780	1.590	0.094	0.234	0.042	0.276
Others	4.093	2.701	5.157	0.365	1.168	1.534
Exotic Fruit	-	-	-	-	47.825	47.825
Exotic Veg	-	-	-	-	5.989	5.989
Total FF&V	**22.412**	**20.697**	**21.597**	**2.885**	**56.404**	**59.290**

Table 3: Datasets and format used in the geographical information system analysis.

Dataset	Format
UK Horticulture statistics, 2019. Department of Environment, Food and Rural Affairs	Excel Spreadsheet
Ordnance Survey, 2019. OS Master Map Greenspace, Accessed from Digimap.edina.ac.uk	Geography Mark-up Language (GML)
Major Towns and Cities, 2015. Accessed from Office of National Statistics	Shape file
Settlements, 2016. Accessed from NRScotland.gov.uk	Shape file

Table 4: Summary of population size, land area (km^2), green space (km^2), calculated productive potential for fresh fruit and vegetables (FF&V) in metric tonnes (MT) and productivity per person in kg for 26 Great Britain (GB) towns and cities, based on the Equal-Split option. Town size classification based on population size: Large>500,000, Medium >100,000, Small<100,000

Size classification based on population size	GB Town or City	Country	Population size	Total Area in km²	*Green Area in km²	Total Productive Potential for FF&V (MT)	Potential Productivity of FF&V per person (Kg)
Large	Birmingham	England	1,160,254	229.13	126.01	224.3	192.2
Large	Edinburgh	Scotland	524,930	125.11	71.79	127.8	242.1
Large	Liverpool	England	586,889	123.31	63.74	113.4	192.2
Large	Bristol	England	577,246	112.46	57.74	102.8	177.1
Large	Leeds	England	511,164	111.63	59.42	105.7	205.8
Large	Cardiff	Wales	354,178	71.38	34.13	60.7	170.6
Medium	Aberdeen	Scotland	228,670	69.44	36.39	64.8	281.7
Medium	Nottingham	England	315,987	62.5	33.75	60.1	189.1
Medium	Plymouth	England	265,792	59.73	29.98	53.3	199.6
Medium	Newcastle upon Tyne	England	287,535	57.9	29.03	51.7	178.7
Medium	Swansea	Wales	185,460	49.08	25.88	46.1	247
Medium	Middlesbrough	England	177,354	49.01	27.77	49.4	277.1
Medium	Bournemouth	England	197,383	40.26	23.13	41.2	207.4
Medium	Sunderland	England	174,807	39.14	18.06	32.1	182.8
Medium	Cambridge	England	148,861	37.62	20.25	36	240.7
Medium	Newport	Wales	136,078	34.72	16.03	28.5	208.5
Medium	York	England	164,369	33.7	16.98	30.2	182.9
Medium	Gateshead	England	122,249	30.17	14.63	26	211.8
Medium	Exeter	England	125,819	27.33	13.52	24.1	190.2
Small	Darlington	England	93,305	22.55	10.85	19.3	205.9
Small	Stockton-on-Tees	England	84,492	21.73	11.09	19.7	232.2
Small	Stirling	Scotland	94,210	21.01	10.69	19	200.8
Small	Burton upon Trent	England	77,536	20.54	9.49	16.9	216.7
Small	Bedford	England	93,378	20.17	10.34	18.4	196
Small	Carlisle	England	74,889	18.92	8.49	15.1	200.7
Small	St Albans	England	87,749	18.66	10.37	18.5	209.2

*The calculation of green space area excludes inland water, foreshores and beaches, and therefore this may vary from other reported figures for land area in these towns and cities. Population data source: ONS (2019)