Landscape Architecture

ARTICLE

Minimum Urban Land Fractions for Import-Exposed Fresh Produce in Great Britain

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Abstract

The resilience of fresh fruits and vegetables in Great Britain goes beyond merely considering the area of urban green spaces. Various crop classes suitable for cultivation outdoors differ in terms of productivity, level of imports dependency, storage behaviour, and urban governance requirements, while exotic produce is always structurally reliant on imports. The current study attempts to calculate the shares of land subject to supply pressure from each of six crop classes of produce suitable for cultivation outdoors. The calculation combines data on crop yield, domestic production, imports, current supply, inferred productive area of urban green spaces, and the town's capacity for the production of crops in question to identify the share of land needed to compensate for the current imports and current supply within each of six compatible crop classes. In this way, land shares have been calculated at 25.9%, 4.7%, 10.4%, 11.5%, 18.2%, and 29.4% for orchard fruits, soft fruits, roots and onions, brassicas, legumes, and other vegetables respectively. National production in case of fully utilised productive potential would amount to 21.568 million tonnes per year – this equals 36.4% of domestic production plus imports and 394.0% of the current supply of the six compatible classes. While the latter figure seems unmanageable, its practical implications are more moderate. Thus, 16.2% of productive green space area in all towns could be sufficient for importing the amount of produce specified, while 32.4% would be needed to produce all this produce domestically. By altering the crop mix in 26 towns/cities, a production volume of 164.2 to 271.1 kg per person per year may be achieved, which surpasses the annual mass equivalent of daily guidelines in all cases.

Keywords: urban horticulture; fresh produce; import dependence; land fraction; green infrastructure; food resilience; Great Britain

1. Introduction

The urban–rural dynamic in food planning involves a clash between built-up space expansion and the preservation of agricultural land. The problem becomes less clear cut when considering towns and cities with considerable vegetated surfaces. Gardens, amenity grassland, allotments, parks, institutional grounds, verges, sports margins, and community-managed plots are not like farmland, yet they can provide land to grow fresh produce if soil is safe,

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access is possible, there is sunshine, there is irrigation, and if there is local approval. Thus, the key question is no longer whether urban green spaces should substitute for agricultural land. The question is how much of the urban land potentially available can grow enough fruit and vegetables to lessen the import dependency of fruit and vegetables most vulnerable to the effects of distance on food security.

This focus on the quantitative dimension of urban fresh produce production becomes necessary in light of increasing urbanisation, rising concerns about food systems and healthy eating, and growing problems related to climate change and environmental degradation [1, 20, 49]. Indeed, while urban expansion alters the spatial relationship between producers and consumers, placing pressure on food chains of highly perishable fresh produce that requires fast processing, refrigeration, transportation, and distribution [25, 30, 35], food security remains a function of international and national food systems and thus susceptible to the same types of shocks. Fruit and vegetables in particular are extremely sensitive, being both highly perishable and vital sources of nutrition in any balanced diet [9, 24].

Great Britain is a particularly interesting national context in this regard, as its population is urbanising rapidly while it depends heavily on food imports in general, and on fruit and vegetable imports in particular. The UK has a long history of importing much of its fruit and vegetables, making itself vulnerable to supply chain uncertainties caused by Brexit, COVID-19, labour shortages, climate change in exporting countries, and changes in consumer demand. [21, 33]. The point here is that while imports play a critical role in securing dietary variety and food supply throughout the year, they expose a food system to supply chain vulnerabilities that arise in cases of interruptions to transportation, labour, borders, and water resources in exporting nations. Urban horticulture is only useful in the context of targeting fruit and vegetables with sufficient import dependence and potential for outdoor cultivation.

Research in urban agriculture has established that urban agriculture holds great potential in terms of food production and social, ecological, and economic benefits. In addition to showing that urban food production can deliver significant crop yields in terms of both quantity and quality, global estimates have found that cities worldwide hold significant productive potential in terms of fresh produce and ecosystem services [6]. City-based studies in Great Britain have found that urban farms can produce sizable amounts of fruit and vegetables, with some achieving yields comparable to commercial horticulture operations [13, 14, 22]. Indeed, urban agriculture has been discussed in terms of the positive impacts on people's engagement with nature, diet, and communities [28, 29, 34, 39]. However, while promising, urban horticulture can also face various challenges related to fragmented ownership, contaminated soils, lack of water, intense labour requirements, unequal access and distribution, and conflicts with biodiversity and recreation [19, 37, 40, 41]. These issues suggest that a targeted approach based on a crop-specific land calculation is needed.

A straightforward land area calculation is inadequate in this situation as not all crops are the same in terms of their contribution to the national food system. Roots and onions provide significantly greater yields than soft fruit or legumes. Orchard fruit and other vegetables are highly imported, whereas soft fruits generate very high value per hectare, albeit a small overall mass of produce. Legumes have low yields and thus require large planting areas, despite having low import volumes. Brassicas lie somewhere in the middle. While a yield-driven calculation will preferentially allocate land to high-yielding crops, a value-oriented calculation will tilt towards highly valuable crops. Meanwhile, allocating land according to current levels of domestic production will simply reinforce existing conventional production patterns. Instead, this study proposes a land fraction calculation based on crop yield, current supply, and import volume, followed by the conversion of the results to dietary sufficiency per town level.

Urban horticulture requires the integration of insights from food security literature on food system resilience, green space research focused on multifunctional urban green space management and urban agriculture that focuses on food production. While food security scholars discuss resilience in the context of capacity to cope with, recover from, and adapt to food system disruptions, urban agriculture tends to be discussed along with other components of urban food systems [26, 50]. Meanwhile, while urban agriculture research provides detailed knowledge regarding the productivity of different food crops, it does not necessarily consider crop exposure to external shocks as defined in national food system terms [42, 44, 45]. Finally, green space literature describes the multifunctionality and governance of urban green space, which poses challenges to assigning land to productive use. [8, 27, 48]. The supply pressure land-fraction calculation integrates all three strands by using horticultural data and then explaining resulting land fractions through green space multifunctionality and governance.

The current study assesses the ability of a crop allocation system based on yield and import volumes to identify a realistic fraction of urban green space that can cover domestic import demand in outdoor-compatible fruit and vegetables in Great Britain. On the one hand, the calculation is conservative since it does not allocate urban land to exotic fruit and exotic vegetables which are unobtainable outdoors in Great Britain. On the other hand, the analysis is expansive in that it considers all available urban land as the basis for production before reducing the results to partial-use fractions. Thus, it tests the usefulness of urban horticulture without overpromising in terms of national food sufficiency.

2. Materials and analytical approach

The study employs data from Walsh et al. [51]. Specifically, crop-yield, production, import, geographical input, and town and city numbers for each of the six crop groups considered here – orchard fruit, soft fruit, roots and onions, brassicas, legumes, and other vegetables – were used in the calculation. These categories of fresh fruit and vegetables are defined and described in the national horticultural statistics summary. In terms of definitions, the group other vegetables follows the broad categorization used by DEFRA. In contrast, exotic fruit and exotic vegetables will be included in the national comparison due to their current existence in the national fresh produce basket, although they are not considered as candidates for outdoor cultivation in Great Britain.

(a) Great Britain. **(b)** Crop groups. **(c)** Urban green space.

Figure 1. National setting.

This national context is provided in Figure 1. Panel one locates the analysis in Great Britain, panel two documents the six crop groups along with their calculated share, and the third depicts the mixed urban environment where gardens, allotments, and grassed open spaces coexist. The separation of the supply problem from the land problem comes prior to their unification in the calculation of the land fraction.

Table 1 presents the crop values applied in the calculation. The yield value is the average yield value over the last twenty years, measured as tonnes per hectare, whereas domestic production and import values are yearly mass measures in million tonnes. The import exposure is computed as the ratio of imports to domestic production plus imports in each of the crop groups. It is seen that the different crop groups vary greatly in terms of contribution to the current supply as well as the area necessary for supplying that supply. In this regard, roots and onions have the maximum yield value of 45 t ha^{-1} along with the greatest domestic production volume out of all six categories. The other vegetables category has the maximum amount of import, being equal to 1.168 million tonnes year^{-1}, and also the highest import exposure equal to 0.762. Orchard fruits also have the highest import exposure of 0.699. The

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minimum yield value of legumes at 4 t ha^{-1} makes them a land-intensive crop despite the low import exposure of 0.152.

Table 1. Crop inputs.

Crop category	Yield, t ha^{-1}	Area, ha	Value, M pounds ha^{-1}	Domestic	Imports	Exposure
Orchard fruit	17	19,983	0.0066	0.341	0.791	0.699
Soft fruit	11	8,954	0.0279	0.102	0.061	0.374
Roots and onions	45	29,648	0.0086	1.334	0.356	0.211
Brassicas	17	29,879	0.0065	0.508	0.172	0.253
Legumes	4	55,125	0.0014	0.234	0.042	0.152
Other vegetables	21	17,026	0.0135	0.365	1.168	0.762

Such an input distribution suggests the need for a crop-based land fraction calculation. One hectare of roots and onions results in more than ten hectares of a corresponding mass compared to legumes. Despite having more yield value than orchard fruit and other vegetables, roots and onions have lower import exposure. Soft fruit has the highest value per hectare, although this type of vegetable represents only a small proportion of the national mass. Consequently, the land fraction calculation must take into consideration exposure, current supply and yield. Considering one of these variables in isolation would produce bias towards a certain production plan.

The analysis above indicates several reasons why the national resilience assessment must consider practical differences between crops and cannot be based on a simple tonnage sum. Root and onion crops differ from the soft fruit in terms of their growing seasons, handling requirements and storage options. Root and onion crops can be stockpiled to sustain supply during seasons in which vegetables of other types are unavailable, whereas soft fruits are very sensitive and thus have to be sold rapidly. The orchard fruit requires perennial investment, which implies that trees are grown slowly but become productive eventually. Brassicas are suited to cool season farming and can extend the window of supply of locally produced food products. Despite being land-intensive under the reported yield value, legumes allow diversification of diets and crop rotation. Finally, vegetables are characterized by high import exposure and a range of crop types, which would necessitate distinguishing protected salads, open-field leafy crops and warm crops in local decisions. These distinctions explain the choice of using land fractions instead of tonnes in the study's estimates of national food resilience.

Table 2 presents a summary of the geographical inputs used in the calculations. The national green-space inventory utilizes OS MasterMap Greenspace data in Geography Mark-up Language format, whereas the information on the crops production/import is obtained from UK horticulture statistics provided by the Department for Environment, Food and Rural Affairs. In the town-level comparison, the major towns and cities boundaries are used for England and Wales, whereas settlements are used for Scotland. Spatial analysis involved excluding inland waters, beaches and foreshore from the list of surfaces. The national green-space inventory has resulted in 18 categories, whereas the initial number of attribute records exceeded 33 million.

Table 2. Spatial and statistical inputs.

Dataset	Format
UK Horticulture statistics, Department for Environment, Food and Rural Affairs	Excel spreadsheet
OS MasterMap Greenspace, Ordnance Survey	Geography Mark-up Language
Major Towns and Cities, Office for National Statistics	Shapefile
Settlements, National Records of Scotland	Shapefile

The spatial data matter, since the productive potential depends not only on total area but also on governance arrangements and parcel form. Private gardens are many, but they are often fragmented and privately owned. Amenity spaces may be substantial in size and suited for coordinated planting, but their attachment to housing or institutional buildings poses limitations. Parks may have substantial surfaces, but they require maintenance of recreational opportunities, shading, accessibility and wildlife. Allotment sites represent the existing experience and resources for cultivation but their combined area is insufficient to constitute the overall urban green space estate. This issue becomes relevant in considering subsequent implications of the land fractions calculated in this study.

Geographical data are also important, since the land fractions presented here are indicative of productive potential but do not suggest a specific allocation policy. The Ordnance Survey greenspace classification is based on functions and forms, but not on all factors that determine productivity. For example, a grass amenity parcel next to houses may be productive if the soil quality allows that and residents support the transformation of this space, and it may be impractical if it is poorly lit, reserved for children's play, or intended for stormwater detention. Parks may offer edge spaces for orchards while the central field remains for recreational activities. Institutional grounds might provide productive land that is easily accessible for irrigation but requires authorization. None of these considerations undermines the national assessment, as such criteria have to be applied at the local level in order to identify productive parcels.

(a) Private gardens.

(b) Amenity land.

(c) Parks.

(d) Allotments.

Figure 2. Green-space settings.

Land setting types depicted in Figure 2 help explain why a numerically defined land reserve cannot be understood as an immediately available agricultural field. While private gardens can provide considerable aggregated area, they depend on active household engagement and distributed advice. Amenity surfaces can be utilised through institutional agreements or housing-estate management. Parks and recreational grounds can provide even larger areas but raise the question of public accessibility and multiple uses. Finally, allottments are already productive,

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although their small national acreage suggests that the supply-resilience scheme will have to cover non-allotment estate lands.

For any crop group i, domestic production is expressed as D_i, imports are denoted by M_i, yield is given by y_i, and present supply equals $S_i = D_i + M_i$. Import exposure of crop group i equals

$$E_i = \frac{M_i}{D_i + M_i}. \tag{1}$$

The production pressure corresponding to each crop group equals

$$T_i = S_i(1 + E_i). \tag{2}$$

This equation allocates greater weights to crop groups with relatively large import exposure without neglecting the absolute supply of each category. A crop group without imports has the same absolute weight as before. Meanwhile, a crop group with imports representing all of its supply will be allotted twice the former weight. Thus, the formula gives additional emphasis to import exposure without ignoring domestic production.

Then, production pressure is transformed to the land share using the division by yield and equalisation to the six crop groups

$$s_i = \frac{T_i/y_i}{\sum_{j=1}^{6} T_j/y_j}. \tag{3}$$

Yield normalisation ensures that the calculation does not prioritise high-yield crops by virtue of mass alone, since this may ignore their role in diet or supply resilience. The total land area of productive greenspace, A_G, is estimated from the equal-division total production of 22.412 million tonnes year^{-1} divided by the six-crop yield average under equal land division, giving about 1.169 million ha. Town-level production can thus be calculated as

$$P_i = A_G s_i y_i. \tag{4}$$

Partial land fractions are calculated using the ratio between each crop and other vegetable categories. The land share needed to match current import volumes in all six crop groups is

$$F_M = \max_i \left(\frac{M_i}{P_i}\right), \tag{5}$$

while the fraction needed to match the sum of domestic and imported supplies in the same crop groups equals

$$F_S = \max_i \left(\frac{D_i + M_i}{P_i}\right). \tag{6}$$

Maximum operation is used to avoid distortion caused by matching supply mass only. The surplus of root and onion production cannot be viewed as a replacement for orchard fruit imports. Similarly, surplus of legumes cannot replace imported salads. Thus, the calculation requires that all crop groups meet the specified supply targets by equalising land shares proportionally.

The transition from import exposure and yield to land share is illustrated in Figure 3. The visualisation clearly demonstrates one of the key features of the calculation: neither the largest import share nor the highest yield defines land shares. Other vegetables and orchard fruits are provided with significant land shares due to high import

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exposure and supply volumes. Legumes get considerable share because of low yield and the need to utilise larger land shares to achieve similar mass. Roots and onions get smaller shares compared to other vegetable groups because of relatively low import exposure despite their importance.

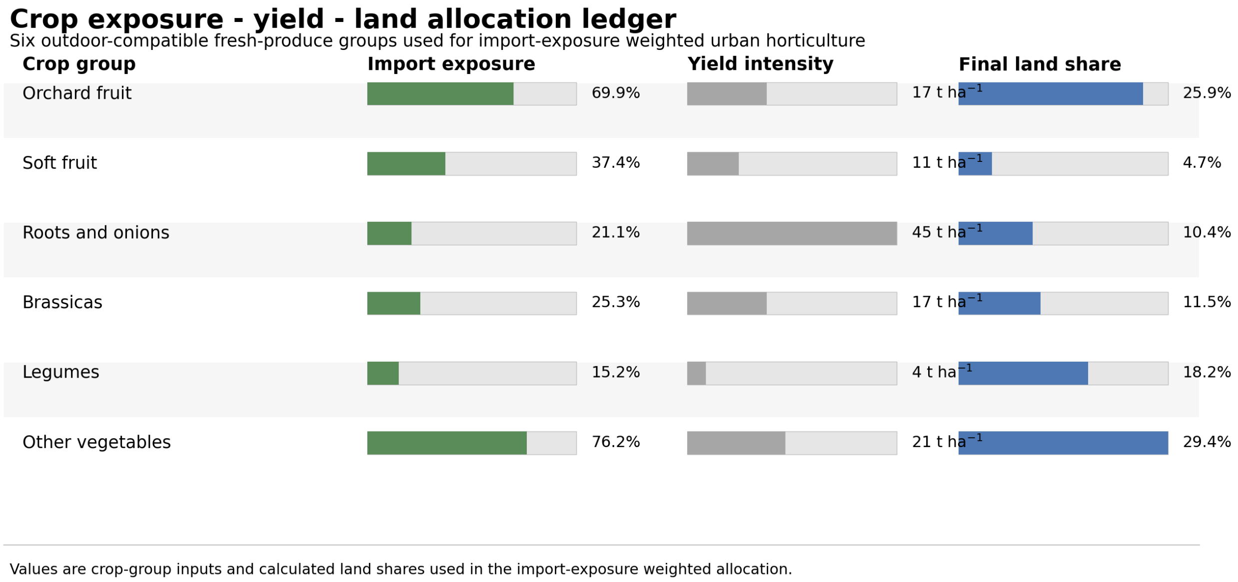

Figure 3. Crop translation.

To assess sufficiency of dietary production capacity for town and city residents, we use 26-town and city table. Adjusted by the ratio between supply-pressure production and equal-division production totals ($R = 21.568/22.412 = 0.962$), the per-person production becomes $K_c = Rk_c$. The annual dietary mass threshold is set at 146 kg person^{-1} year^{-1}, equivalent to 400 g person^{-1} day^{-1} within a year [18]. Thus, the share of productive capacity needed to reach that threshold is $146/K_c$.

3. Results

Supply-pressure calculation provides two crop groups, i.e., other vegetables and orchard fruits, with the largest land shares due to their relatively high import exposure. In particular, other vegetables account for 29.4% of productive greenspace and orchard fruits for 25.9%. Due to low yield, legumes account for 18.2%. Brassica gets 11.5% land share; roots and onions, 10.4%; and soft fruits, 4.7%. Despite high value per hectare, the latter crop group receives only a limited share owing to low present supply volume.

Table 3 shows that productive greenspace will generate 21.568 million tonnes year^{-1} when being employed according to the supply-pressure criterion among all six crop groups. Note that the calculation does not yield the maximum production. Indeed, if a land assignment is made in favour of root and onion cultivation, the mass of the product would be greater because of high yield (45 t ha^{-1}). However, such a land distribution would be less sensitive to import exposure. The current mass total, therefore, can be seen as a compromise between supply volume and exposure. Each crop group will surpass its current imports under productive use, but the surplus should not be viewed as immediately exploitable. Harvesting, storage, processing, delivery, labour needs, and consumer preferences determine how much of that production will be available without losses.

Comparison of the above values to those produced in the previous calculations is given in Table 4. Supply-pressure production total is close to that of the value-led approach but below that obtained in equal division. The reason is that, unlike other land divisions, it accounts for both import exposure and current supply volume after yield normalisation.

Table 3. Land shares and production.

Crop category	Pressure share	Land share	Production, million tonnes year^{-1}	Production divided by imports	Production divided by present supply
Orchard fruit	0.238	0.259	5.143	6.50	4.54
Soft fruit	0.028	0.047	0.599	9.82	3.68
Roots and onions	0.254	0.104	5.472	15.37	3.24
Brassicas	0.106	0.115	2.279	13.25	3.35
Legumes	0.039	0.182	0.851	20.25	3.08
Other vegetables	0.335	0.294	7.224	6.19	4.71
Total	1.000	1.000	21.568	–	–

Table 4. National production comparison.

Land division	Total production, million tonnes year^{-1}	Share of all domestic production plus imports	Share of six-group domestic production plus imports
Equal division	22.412	37.8%	409.4%
Domestic-production division	20.697	34.9%	378.0%
Value-led division	21.597	36.4%	394.5%
Supply-pressure division	21.568	36.4%	394.0%

The difference lies in the denominator. For all fruit and vegetables combined, total production and imports add up to 59.290 million tonnes per year, and supply pressure urban production amounts to 36.4% of that figure. If the denominator consists only of the six compatible groups, current supply totals 5.475 million tonnes per year, and the same output constitutes 394.0%. In the first case, there are no illusions about full self-sufficiency with the whole basket of products, since exotic fruit imports alone add up to 47.825 million tonnes per year. In the latter case, the availability of urban land becomes clear, relative to the range of crops that can be grown outdoors.

As such, the national figures need to be understood in several steps. The all-supply percentage can be called a food system exposure number, since it preserves visibility of the total basket of fruits and vegetables. The compatible-supply percentage should be interpreted as an agronomic opportunity number, since it eliminates fruit and vegetable categories that cannot be grown under local conditions outdoors. The land-fraction percentages mentioned later bring opportunity numbers to a policy level. This multi-step approach is necessary for keeping both pessimistic and optimistic assessments on track. On one hand, the former might emerge from evaluating urban horticulture according to all fresh-produce imports. On the other hand, the latter might result from overstating opportunities for compatible crop production.

The difference shown in Figure 4 avoids a possible misinterpretation of the national aggregate. While a high production quantity in relation to the compatible crop categories implies that the contribution of urban agriculture cannot compensate for produce like bananas, avocados, grapes, sweet potatoes, among others that do not grow in such environments, it also implies that the compatible produce types have enough potential related to land usage to consider them seriously when designing a fresh produce resilience strategy.

The partial use factors are by far the most valuable outcomes of the calculations since complete conversion of the available urban green space into farmland is both undesirable and unrealistic. The import equivalent ratio is

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constrained by the most limiting of the crop categories after normalizing the values proportionally, just like the domestic plus import factor. Table 5 gives the land proportions for each category sufficient to meet its respective imports and supply ratios.

(a) All supply. **(b)** Compatible groups.

Figure 4. National production scale.

Table 5. Crop-level land fractions.

Crop category	Fraction to match imports	Fraction to match present supply	Controlling interpretation
Orchard fruit	15.4%	22.0%	high import exposure
Soft fruit	10.2%	27.2%	small mass, high value
Roots and onions	6.5%	30.9%	high yield, large supply
Brassicas	7.5%	29.8%	intermediate demand
Legumes	4.9%	32.4%	low yield controls supply
Other vegetables	16.2%	21.2%	imports control exposure

These crop level thresholds suggest that the import exposure target and the entire present supply target are driven by different classes of crops. To match the current imports for all compatible classes would take up 16.2% of the productive land since other vegetables have the highest proportion of imports relative to their respective production levels. On the other hand, matching imports and domestic production needs about 32.4% of the productive land area, which is dominated by legumes due to its low yield at 4 t ha^{-1}. The implication of this is that there is a change in policy advice from total conversions to selective partial cultivation schemes. An effective programme that can bring into use about one-sixth of suitable urban green land areas will help to match the imports of these compatible groups. About one-third of the productive land would match the entire present supply of the compatible group.

This crop-by-crop threshold table shows how an implemented programme may be structured. Early implementation may focus on other vegetables and orchards due to their dominance over the import exposure targets while roots and onions may prove as dependable sources of reliable storage crops and a visible harvest. Caution should be exercised for legumes since they drive the entire supply of the compatible group but have low yields compared to other types; thus it is more appropriate to integrate them via rotations and fertility of soils. It would be advisable to concentrate soft fruit within high-value land areas with adequate labour supply and picking ability.

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(a) Import equivalent.

(b) Full compatible supply.

Figure 5. Partial land fractions.

Table 6. City sufficiency.

Class	Town or city	Country	Pop.	Land, km^2	Green, km^2	Green, %	Equal kt	Equal kg	Adjusted kg	Capacity for 146 kg
Large	Birmingham	England	1,160,254	229.13	126.01	55.0	224.3	192.2	185.0	78.9%
Large	Edinburgh	Scotland	524,930	125.11	71.79	57.4	127.8	242.1	233.0	62.7%
Large	Liverpool	England	586,889	123.31	63.74	51.7	113.4	192.2	185.0	78.9%
Large	Bristol	England	577,246	112.46	57.74	51.3	102.8	177.1	170.4	85.7%
Large	Leeds	England	511,164	111.63	59.42	53.2	105.7	205.8	198.1	73.7%
Large	Cardiff	Wales	354,178	71.38	34.13	47.8	60.7	170.6	164.2	88.9%
Medium	Aberdeen	Scotland	228,670	69.44	36.39	52.4	64.8	281.7	271.1	53.9%
Medium	Nottingham	England	315,987	62.50	33.75	54.0	60.1	189.1	182.0	80.2%
Medium	Plymouth	England	265,792	59.73	29.98	50.2	53.3	199.6	192.1	76.0%
Medium	Newcastle upon Tyne	England	287,535	57.90	29.03	50.1	51.7	178.7	172.0	84.9%
Medium	Swansea	Wales	185,460	49.08	25.88	52.7	46.1	247.0	237.7	61.4%
Medium	Middlesbrough	England	177,354	49.01	27.77	56.7	49.4	277.1	266.7	54.7%
Medium	Bournemouth	England	197,383	40.26	23.13	57.5	41.2	207.4	199.6	73.2%
Medium	Sunderland	England	174,807	39.14	18.06	46.1	32.1	182.8	175.9	83.0%
Medium	Cambridge	England	148,861	37.62	20.25	53.8	36.0	240.7	231.6	63.0%
Medium	Newport	Wales	136,078	34.72	16.03	46.2	28.5	208.5	200.7	72.8%
Medium	York	England	164,369	33.70	16.98	50.4	30.2	182.9	176.0	82.9%
Medium	Gateshead	England	122,249	30.17	14.63	48.5	26.0	211.8	203.8	71.6%
Medium	Exeter	England	125,819	27.33	13.52	49.5	24.1	190.2	183.0	79.8%
Small	Darlington	England	93,305	22.55	10.85	48.1	19.3	205.9	198.1	73.7%
Small	Stockton-on-Tees	England	84,492	21.73	11.09	51.0	19.7	232.2	223.5	65.3%
Small	Stirling	Scotland	94,210	21.01	10.69	50.9	19.0	200.8	193.2	75.6%
Small	Burton upon Trent	England	77,536	20.54	9.49	46.2	16.9	216.7	208.5	70.0%
Small	Bedford	England	93,378	20.17	10.34	51.3	18.4	196.0	188.6	77.4%
Small	Carlisle	England	74,889	18.92	8.49	44.9	15.1	200.7	193.1	75.6%
Small	St Albans	England	87,749	18.66	10.37	55.6	18.5	209.2	201.3	72.5%

The two thresholds in Figure 5 should probably be interpreted as targets for land-fraction rather than instructions on conversion. The 16.2% figure represents the point at which the amount of imported mass could match that of the compatible crops. The 32.4% figure represents the point at which the mass of current production plus imports could match for the compatible groups. In each case, much of the green-space remains unused in the productivity equation, and that is an important factor because the green spaces of towns and cities provide other functions such as recreation, cooling, tree cover, biological diversity, stormwater management, and social amenities. There should be more selective use than full conversion.

The assessment of the town and city calculation determines whether the combination of crop types creates local dietary insufficiencies due to supply pressures. The adjustment ratio of 0.962 decreases the equal-division per person values since the combination includes some low yield land. However, after the reduction in equal division values, all of the towns and cities still exceed 146 kg person^{-1} year^{-1}. These values vary between 164.2 kg person^{-1} year^{-1} for Cardiff and 271.1 kg person^{-1} year^{-1} for Aberdeen (Table 6).

As one may observe from the city values, the level of dietary sufficiency does not necessarily correlate with the number of inhabitants. Edinburgh, for example, as a relatively populous city, has significantly higher adjusted per capita value than Cardiff and Bristol. Aberdeen and Middlesbrough have the largest adjusted values due to high share of green areas per inhabitant. Cardiff is still above the threshold, but it takes 88.9 percent of the adjusted production capacity of the city to provide 146 kg person^{-1} year^{-1}. Meanwhile, Aberdeen needs 53.9 percent. Such variability shows that the country's crop priorities may be divided, yet different types of land use should apply to specific urban settings.

These findings are also useful when interpreting the results in terms of public health. Indeed, we calculate the total mass value based on 146 kg person^{-1} year^{-1} which corresponds to 400 g daily intake of fruits and vegetables as suggested by the guideline, rather than stating that each resident will eat the produce grown in the city. Diet improvement depends on various factors, including food cost, accessibility, cooking conditions, preferences, availability of time, etc. Nonetheless, the excess of the mass threshold provides greater possibilities for creating appropriate distribution channels. The public kitchen, school cafeteria, food bank, local market, and other options require the same area but allocate it in a different way.

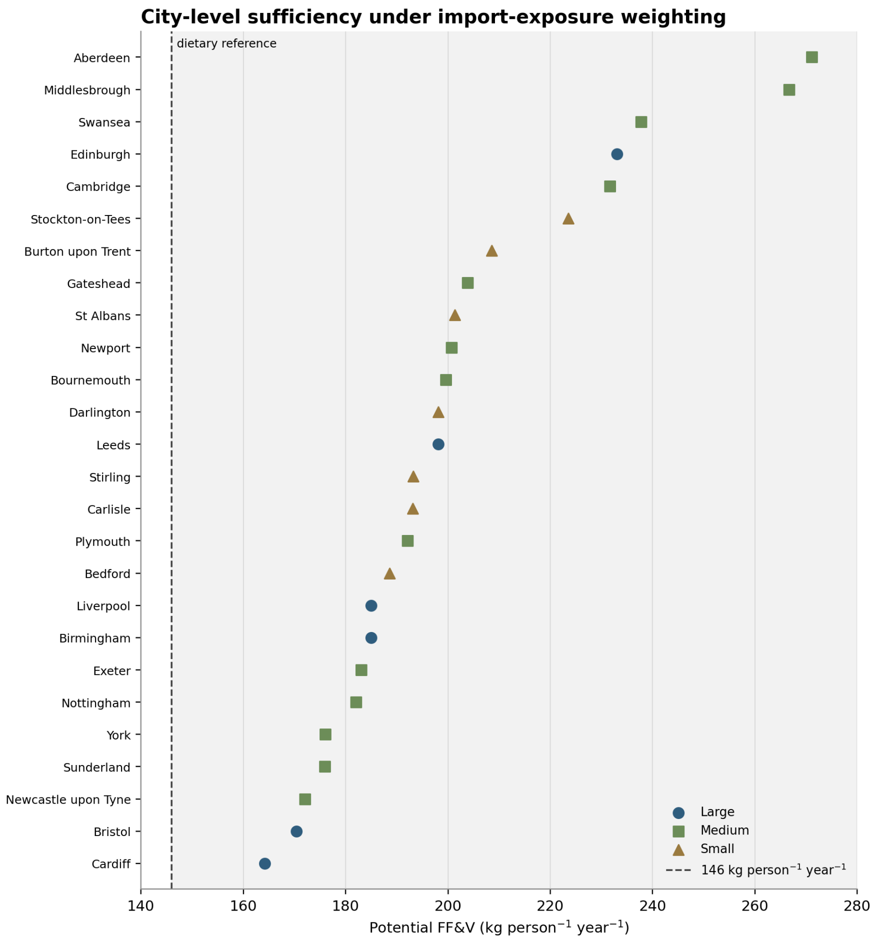

Figure 6. City sufficiency.

The distribution in Figure 6 further emphasizes the importance of reading the table results correctly. All cities fall to the productive side of the annual dietary mass threshold. Margins are largest in Aberdeen, Middlesbrough, Swansea, Edinburgh, and Cambridge. Narrower margins apply in Cardiff, Bristol, Newcastle upon Tyne, Sunderland, York, and Nottingham. The variation suggests that urban horticulture policy should not prescribe a standard land allocation for all settlements. The cities with high reserve capacity may consider all options for land selection, including allotments, community orchards, park edge cultivation, school gardens, and institution sites. The cities with narrow reserve capacity may need to select parcels carefully.

Roots and onions would have the highest storage capacity among all four compatible groups shown, while orchard fruits are likely to have relatively lower storage capacity due to their seasonal characteristics. Orchards would require perennial management as well as post-harvest storage or processing facilities. Salad vegetables and soft fruits have relatively high perishability levels and would therefore require efficient harvesting as well as rapid distribution.

Agricultural balance on the basis of individual crop groups is visualized in Figure 7. The plot reveals that even a productive full-use strategy would generate a surplus in every compatible crop group over both present imports and present supply volumes. That information provides important guidance about the scale of possible impact, but it requires caution. Crop groups with excess capacity relative to domestic consumption are only useful if the infrastructure of harvest, storage, preservation, processing, distribution, and consumer access are all in place. Hence, it makes more sense to read the zones as signals of post-harvest management priorities, with different groups requiring storage and seasonal adjustment.

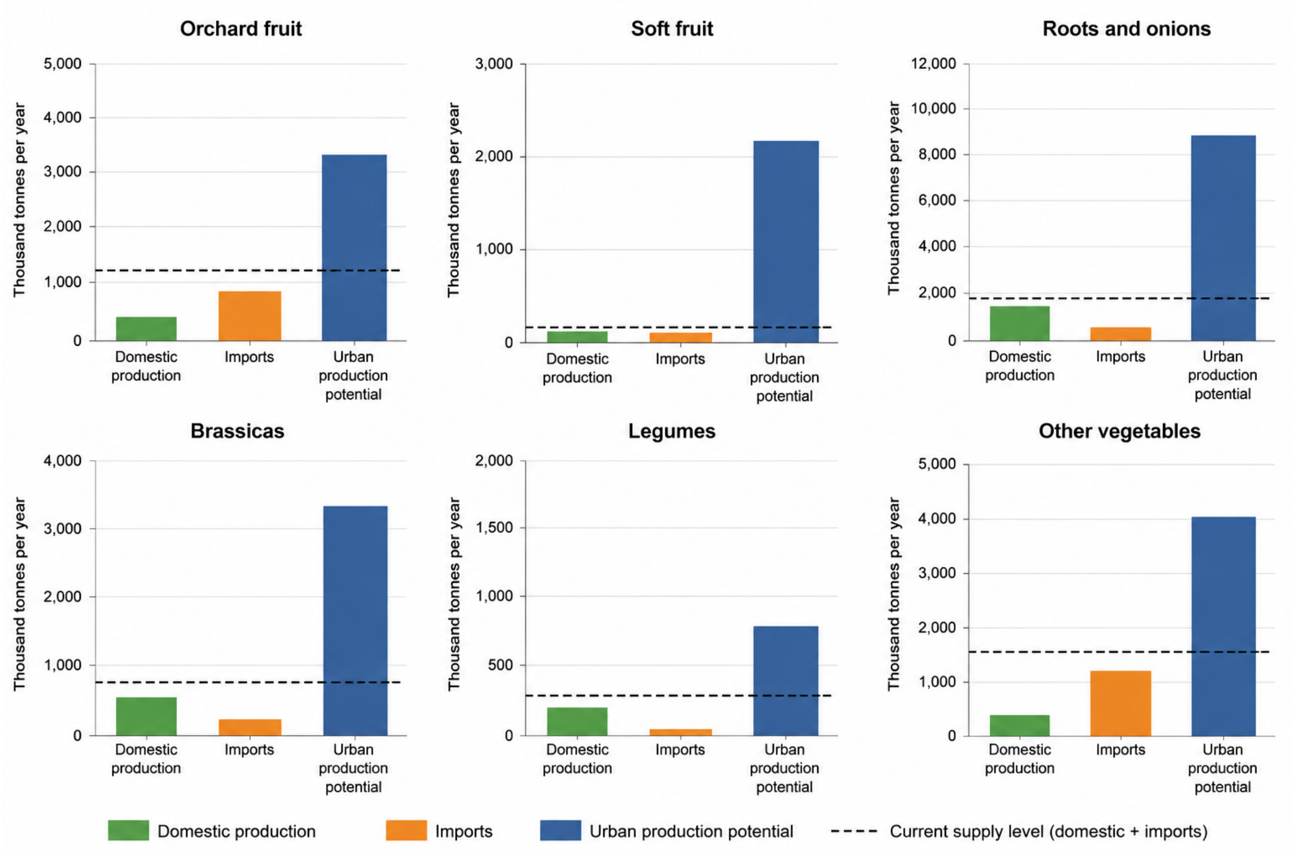

Figure 7. Crop-level production balance.

4. Discussion

As discussed in the introduction, the findings offer direct answers to the central research question. By calculating supply pressure according to both imports and yield for the crop groups that have high compatibility scores, we can obtain a partial urban land fraction with enough productive capacity to matter for import resilience, but without requiring complete conversion of green space. The 16.2% land fraction can be considered the primary outcome of this study because it refers to the imported portion of the six compatible crop groups. The figure suggests that one-sixth of the productive urban green space can equal the current imports of orchard fruit, soft fruit, roots and onions, brassicas, legumes, and other vegetables with the specified yield assumption.

The 32.4% land fraction corresponds to the more challenging target of matching the current supply volumes in the six compatible groups. These results imply that urban horticulture planning would need to operate with both national guidance (which prioritises crop groups and highlights yield targets) and local site selection that matches the identified goals with adequate agricultural potential.

These conclusions distinguish the calculation from the urban agriculture argument. The idea of using urban land for agriculture is often promoted as an answer to food security problems, but the total amount of green space per city or country is only the starting point for the solution [36]. The actual questions are which fraction of the total can be converted to agricultural use, which fraction is accessible, suitable for cultivation, and which fraction can be effectively managed. The supply-pressure calculation provides guidance about the first two issues.

The calculation is distinguished from a pure yield-maximization argument because a dominant focus on roots and onions would increase mass tonnage, but would not address the problem of import exposure in other vegetables and fruits. A focus on the other vegetables would maximize market value per tonne, but would neglect the supply-weighting step, thus failing to respond to the large mass of compatible import volumes. By combining both criteria, our model captures a supply-pressure target that is feasible for land conversion.

Comparison with previous studies is important in evaluating the findings. The global literature on urban agriculture has found that large amounts of green space can be converted for productive purposes and that such conversion would be feasible to accomplish [6]. Local estimates in British settings confirm the usefulness of allotments and own-growing in meeting production goals [13, 14, 22]. However, in the UK setting, such estimates need to account for local conditions as well as national crop composition. Our calculation demonstrates that national guidance can be precise in identifying import-exposed crop groups, while local planning is still responsible for crop selection and management.

The denominator issue plays a crucial role in avoiding overstatement. The supply-pressure output equals 36.4% of all domestic production and imports in the fresh-produce basket only because the denominator covers the total volume of all exotic fresh produce. On the contrary, the supply-pressure output equals 394.0% of current supply volume in the six compatible groups only because this denominator is smaller and agronomically reasonable. Thus, while these values are equally valid and correct, they serve different purposes. The first proves that urban horticulture cannot substitute the whole basket. The second proves that it can play a major part in ensuring resilience of selected groups.

Crop-specificity has implications for post-harvest planning. Other vegetables dominate the supply pressure result, and for good reason, since this category includes a wide range of exotic products with different storage requirements. Legumes drive the supply-demand output because of low domestic yield. While roots and onions are not highly exposed to imports, they have high yield capacity and storage potential, allowing for winter production. Orchard fruits have great potential in terms of reducing imports, although their planting requires multi-year efforts, pruning, pest management, and careful care until mature. Finally, soft fruits are high-value and dietary, yet they are perishable and require intensive cultivation.

Urban governance is likely to determine whether the identified numerical potential will be feasible. Private gardens are an important collective resource, but whether they will be accessible for agricultural cultivation depends on households' willingness, tenancy status, time availability, and expertise as well as distribution across the urban population. Policies focused on the use of residential gardens would be likely to favor households with private land, security of tenure, and free time. Amenity green spaces and institutional grounds can provide a more organized setting, although management and maintenance contracts, liability, soil quality, and long-term commitment would need to be negotiated and coordinated. Existing allotments have a rich experience in horticulture, but the total volume of this category is not enough for a supply goal.

(a) Residential gardens.

(b) Public parks.

(c) Institutional land.

(d) Allotments.

(e) Community space.

Figure 8. Land access contexts.

The governance environments described in Figure 8 reveal the reasons why urban agriculture policies should be diverse and context-driven. Residences can accommodate distributed gardening, seedling growing, tree fruit growing, composting, and household consumption. Public parks can host orchards, perennial planting, demonstration gardening areas, or community-growing low-fences in order to keep public access functional. Institutional green spaces can link schools, health clinics, universities, and government agencies to create food education and local procurement opportunities. Allotments are already a well-developed agricultural environment and can play the same role. Finally, community-managed land is likely to facilitate access for households lacking home gardens while promoting participation in social activities.

Combining several environments increases the chances of effective implementation and allows for diversifying crops. The proposed model does not allocate land to crops, but a sensible agricultural scheme would need to ensure that high-perishability products are placed on sites with easy harvesting and distribution logistics. Moreover, perennial fruit trees would be incompatible with temporary or insecurely maintained sites. Products with storage potential can be placed on institutional or community sites where harvest handling can be organized, whereas high-preference garden vegetables can be grown for direct consumption by families.

Monitoring is required to avoid misrepresentation of the agricultural output. In fact, there is little sense in measuring the quantity of gardens and the total amount of planted vegetables if the monitoring does not include crop group, cultivated land, harvest tonnage, spoilage rate, post-harvest storage routes, distribution, soil test status, and the fraction of produce allocated to consumption in households, sale, donation, and public kitchens. Such monitoring would prevent overstatement and would also allow further improvements of the calculation in terms of loss rates, seasonality, nutrient concentration, and social accessibility.

Finally, import reduction should be interpreted with caution. Domestic production can certainly reduce purchase of imported goods, if produced crops are consumed, sold, or distributed through channels that replace imports [2, 16, 47]. Production that is unused, poorly stored, or inaccessible to the residents does not contribute to the desired reduction of imports. That is why the reported figures are calculated with reference to import exposure rather than actual reduction of imports. In particular, 16.2% represents the land fraction corresponding to mass equivalence of compatible import volumes, and its feasibility hinges on timely harvest, preservation, and distribution.

5. Methodological limitations and implementation challenges

First of all, the calculation method is national and group-level. Thus, it cannot specify particular plantations to any individual parcel. Each of the compatible crop groups contains multiple species or varieties, all with different seasonality, storage capacity, labour requirement, pest pressures, and nutrient content. Other vegetables are especially heterogeneous in this respect, requiring separation into salads, peppers, cucurbits, leafy vegetables, etc. Orchard fruit requires separation due to the long process of tree establishment, rootstock selection, pruning, pollination, and delayed maturity.

Second, national yield estimates provided for this model are averages, which do not necessarily correspond to actual performance at parcel level. High yields are often achieved with intensive management, intercropping, frequent harvests, and soil enrichment [12, 37]. Lower yields are often encountered due to insufficient sunlight, excessive shade, poor soil, insufficient labour input, pest infestation, vandalism, limited water supply, unsuitable microclimates, or poor location of parcels. Our findings can be used for initial national estimates, with follow-up yield testing in localities before allocating land.

Third, urban green space estimated by dividing productive use by average yield is an approximation that is acceptable for national calculations based on published figures. Local agricultural planning would require detailed information on land tenure, soil contamination and quality, slope, sunlight hours, tree coverage, accessibility, environmental designations, and water access. Also, our calculation implies that compatible crop mix can be applied to all urban environments. Actually, each local setting would need to take into account climate effects (such as exposure to the sea, frost patterns, rainfall), soil types, heat islands, and preferences of residents.

Fourth, the annual dietary threshold is measured in tonnes per capita. Meeting the annual requirement does not mean that produce consumed is nutritious and diverse or that distribution is equitable and accessible. A smaller volume of nutritious produce donated to households with poor accessibility would provide more nutritional benefits than a larger volume for already food-secure residents. Future research needs to consider nutrition and social access alongside mass.

Fifth, our supply-pressure formula assigns equal numerical weight to domestic present supply volumes and import exposure. A larger coefficient would shift the target towards highly imported crops, while a smaller coefficient would move it towards present supply. If necessary, policy makers could include factors like seasonal storage, nutritional content, water requirement, labour requirement, and soil suitability for cultivation. Our formula combines volumes, import shares, and yields, making each factor traceable and reproducible.

6. Conclusions

The core of our research question was whether import-dependence and crop yield estimates can be combined to derive a practical land fraction to improve resilience of fresh produce in Great Britain. The conclusion of this study is that yes, import-exposure and yield data allow deriving urban green-space targets for fresh produce with high domestic yield potential. Our supply-pressure algorithm allocates land to other vegetables and orchard fruits, due to their combination of high import exposure and present supply volumes with roots and onions, brassicas, legumes, and soft fruit included.

The national estimate is large, but bounded in terms of mass tonnage. Complete productive use of the land fraction would give 21.568 million tonnes per year, which is 36.4% of total present production and import and 394.0% of present domestic supply volume in the six compatible groups. In the interest of urban horticulture policy-making, the more useful figures are 16.2% of the land fraction (matching compatible import volumes) and 32.4% (matching supply volumes).

Our city-level calculation confirms that the supply-pressure allocation is sufficient to meet the annual dietary mass threshold. In the 26 cities studied, adjusted dietary mass estimates remain above 146 kg/person/year in all cases, ranging from 164.2 kg/person/year in Cardiff to 271.1 kg/person/year in Aberdeen. The reserve varies significantly, but is unlikely to negate the national result.

Finally, urban horticulture can neither substitute imported exotic crops nor solve food security by converting green space into land for crops. Its strongest contribution lies in providing partial, specific, and locally managed addition to national resilience by aligning import-exposed crops with suitable urban land, soils, growers, storage facilities, distribution networks, and equitable access. Our report translates this contribution into numerical land fractions.

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