Potential ecosystem services of urban agriculture: a review

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Abstract

Urban agriculture (UA) is increasingly proposed as an environmentally friendly answer to global challenges including urbanization, public health, food security and climate change. We provide an overview of present evidence of ecosystem services delivered by UA that could potentially increase the sustainability of the urban ecosystem, including the often claimed reduced greenhouse gas emissions. There is general agreement that UA is important for local food production, especially in the south; that UA has a role in regulating green and blue water flows, organic waste flows and pollination; and that UA has important socio-cultural values, including an improved quality of city life and increased local community capacity. There is some evidence that UA may also improve human health because of dietary changes in certain social classes, but these are potentially confounded by environmental pollution in the city. Quantitative evidence is very limited for all ecosystem services, but the available data nevertheless suggests that the overall food productivity and the total reductions in greenhouse gas emission are low at global or city-wide scale despite the fact that UA has potential strong effects on food security at the local scale. The current eagerness of industrialized cities to integrate UA into their food policies as an approach to become "climate neutral" or to rely on ecosystem services to become more resilient calls for life cycle assessment studies that accurately quantify emission reductions and other urban ecosystem services of urban agriculture.

Introduction

Urban agriculture (UA) is an alternative farming system based on small-scale local food production in an urban or peri-urban setting, and which often, but not necessarily, uses organic techniques and the principles of environmental sustainability. UA is a common source of income and coping mechanism in many cities in developing countries (e.g. De Bon et al. 2010; Lee-Smith 2010). Recently UA is also expanding in industrialized countries, with Canada, the United States, Australia and the United Kingdom showing most public interest (e.g. Lanarc-Golder 2013). The recent increase in popularity of UA in these regions has three major drivers: (1) the awareness that the projected world population of nearly 10 billion people by 2050 brings serious challenges to global food security; (2) the probability that, by 2050, 70% of the world population will live in a city; and (3) the perception that producing food locally in cities enhances ecosystem services, reduces environmental impacts of the built-upon systems (Mason and Knowd 2010; Grewal and Grewal 2011) and increases resilience (Barthel and Isendahl 2013). Advocates of UA seek consumer support by highlighting the environmental benefits of UA, such as reduced greenhouse gas emissions and enhanced biodiversity in cities. However, scientific evidence of these services and benefits is very limited as with other urban green infrastructure (Pataki et al. 2011; but see Kulak et al. 2013). Nonetheless policy makers at various levels are increasingly interested in UA (see e.g. Lang 2014), for example as a means to comply with policy guidelines for sustainable development. For this reason, the European Union has launched COST actions on UA and on urban allotment gardens, and the United Nations has its own Food for the Cities program. At the same time, ecosystem services (ES) (MEA 2005) are emerging as guiding principles in urban planning (Niemela et al. 2010; Gómez-Baggethun and Barton 2013) and in agriculture (Power 2010). Here we review current evidence of ecosystem services delivered by UA that could contribute to an increased sustainability in urban ecosystems and identify knowledge gaps.

A typology of urban agriculture

UA is the collective name for a wide variety of farming activities that occur within the boundaries of a city or within the direct sphere of influence of a city (Table 1). UA can develop on residential lots, within urban and public green spaces, on vacant lots or residual agricultural land within the city (e.g. Fig. 1a) (Taylor and Lovell 2012; Lanarc-Golder 2013). Land can be privately owned (e.g. an urban backyard, Fig. 1b), leased by individual tenants or communities (e.g. allotment gardens, Fig. 1c,d) or belong to the public space (Fig. 1e-g). Farming systems may be temporary or

Table 1. Typology of urban agriculture

Type	Description
allotment garden	Plot of land subdivided in small parcels that are assigned to and cultivated by individuals or families, usually peri-urban; in the USA also known as community garden
community garden	Plot of land cultivated collectively by a group of people
community-supported agriculture (CSA)	Plot of land cultivated by one or more dedicated farmers for subscription customers that may assist in tending or harvesting; also applies to the association between consumers and local growers that have agreed to share the risks and benefits of local food production
container garden	An array of containers, usually plastic or geo-textile, in which vegetables are grown
edible green roof	Roof of building partially or completely covered with substrate in which vegetables are grown; also applies to container gardens or hydroponic systems placed on roofs
floating farm	Container garden or hydroponic system placed on barge
private garden	Private plot of land partially or completely cultivated by an individual or family, known as backyard (or frontyard) when attached to private house
hydroponic system	Soil-free greenhouse agriculture in which irrigation water and nutrients are intensively re-used
pavement garden	Very small and extensively or intensively planted vegetable garden replacing impervious surfaces on public terrain
rooftop farm	Vegetable farm using containers, raised beds, hydroponic systems or engineered soil placed on roof of a building
square foot garden	Small but intensively planted, often multi-layered vegetable garden, often in raised beds or in containers
windowsill farming	Growing vegetables in containers on the windowsill or balcony

permanent, on a large or a small scale, and focus on monocultures or polycultures with varying degrees of technological complexity (e.g. from simple flowerpots to complex, engineered rooftop gardens, Fig. 1g). A shared feature among many UA types is a limitation in space: horizontally (e.g. the limited area of square foot gardens; Fig. 1h), vertically (e.g. the limited soil depth in rooftop gardens; Fig. 1g), or both (e.g. container gardens; Fig. 1f). This typology clearly shows that farming is generally not the main function but an emerging secondary function in the urban ecosystem.

Provisioning services of urban agriculture

The provisioning of food, in particular vegetable crops, small fruit, aromatic spices, eggs and poultry, is the most obvious provisioning service of UA (Table 2). The small scale of UA allows urban farmers to use old or non-commercial varieties and land races, which is beneficial for the conservation of crop genetic resources (Galluzzi et al. 2010). Because there are concerns of pollution and infectious diseases (e.g. *Salmonella*), livestock is much less frequently raised in UA (Pollock et al. 2012).

A recent model based on the average annual diet in The Netherlands estimates that an average large city in Europe (1 million inhabitants) has an environmental “foodprint” (Stedelijke Foodprint 2012) (i.e. ecological footprint of providing these inhabitants with the food for their diet) of 83,000 ha (18,000 ha for crops; 46,000 ha for animal fodder and an equivalent of 19,000 ha land for imported fodder for a total of 2.5 million animals). If it would be possible to grow all fresh produce within the city boundaries, the share of UA in urban food security would be only 3% (i.e. 1,000 ha fruit and 1,400 ha vegetables; a total urban production of 2,400 ha). A variety of intensive UA scenarios run for the city of Cleveland showed that 4 % of the required food mass could be produced in UA when 80% of every vacant lot was used for UA. Cleveland could produce 18% of the required food mass when in addition to the 80% vacant lots also 9% of every residential lot and 62% of every industrial and commercial rooftop was used for UA (Grewal and Grewal 2011). In Oakland, 6.5% of all space with agricultural potential would contribute between 2.9 and 7.3% of Oakland’s current consumption, depending on the used production methods (McClintock et al. 2013). Quantitative estimates are scarce and show high variability, but nevertheless, the current evidence suggests that in industrialized countries UA can only make a limited contribution to improving food self-sufficiency at the city scale. In southern developing countries, the provisioning services of UA seem to be more important (Ashebir et al. 2007; De Bon et al. 2010; Zessa and Tasciotti 2010; Lynch et al. 2013; Clarke et al. 2014) but quantitative data is lacking.

Regulating services of urban agriculture

Regulation of air quality, local climate and water: Urban green infrastructure has important potential to adapt cities to climate-related impacts (Gaffin et al. 2012), for instance through its regulating services which include air quality regulation, local climate regulation and water regulation (Pataki et al. 2011). Air quality regulation of urban green depends primarily on the ability of plants to absorb or attract particles and pollutants and this increases with increasing leaf-area-index (LAI). This is a very useful service of urban trees (Pugh et al. 2012) but a rather undesired property of plants parts that are grown to be consumed. Although direct contamination of UA crops by polluted air may be limited because of the limited leaf area index of vegetables (but see Bell et al. 2011), there are also health risks associated to soil pollution, through atmospheric deposition of heavy metals and other toxic compounds (Alloway 2004; Nabulo et al. 2012).

Figure 1. Examples of urban agriculture (UA)

Persistent UA: (a) corn field in an office park (Leuven); Traditional UA: (b) backyard (Leuven); (c) private organic allotment garden (Leuven); (d) community garden (East New York Farms!, New York); Emerging UA: (e) pavement garden (The Edible Bus Stop, London); (f) community container garden (Prinzessinnengarten, Berlin); (g) public rooftop container garden (Potage-Toit, Brussels); (h) private rooftop square-foot garden (Brussels); (i) commercial rooftop farm (Brooklyn Grange Farm, New York); and (j) experimental floating farm (The Science Barge, New York). Images reproduced with permission.

Also, the long-term effects on human health of the consumption of UA produce are currently unknown (Brown and Jameton 2000). Health effects of UA are likely to differ widely between different social classes, with poor citizens relying on UA for subsistence, in particular in the south. This means that the potential health benefits of UA – the improvement of consumer diets – is possibly confounded by the harmful effects of pollution (Douglas 2012).

Through increased infiltration and higher evapotranspiration, vegetation cover in the city cools the atmosphere, and reduces blue water flows (Coutts et al. 2012). Theoretically, UA thus has a positive effect on water and energy flows compared to built-up surfaces, but trees or other plants with high LAI are expected to be much more effective in mitigating the heat island effect of cities or controlling peak water flows (Coutts et al. 2012; Hall et al. 2012), also because most crops can only exert temporary effects on their environment. Nevertheless, Whittinghill et al. (2014) recently documented that vegetable producing extensive green roofs had a similar water retention capacity than more conventional *Sedum* green roofs.

Global climate regulating services: Global climate regulation through carbon sequestration is obviously very limited in crops, certainly when considering that even urban forests have limited carbon mitigation potential (Strohbach et al. 2012). Nevertheless, UA may have an impact on global climate through the reduction of "*food miles*" – the environmental impact of food related to transport. The average food crop is transported long distances (> 2000 km) from farm to consumer (Grewal and Grewal 2011), needs packaging and storage, and suffers considerable losses in the supply chain (2-33%, according to a review by Parfitt et al. 2010). Reducing such losses and transport steps by producing food locally can reduce overall emissions compared to the conventional food chain. However, reduction of transport distances and losses might not always result in a net climate change benefit over the complete life cycle of UA products (Edwards-Jones 2010). Studies in the UK and China have shown that the direct emissions of agricultural practices are by far the largest share of the footprint of food production (and thus, not the transport; Vermeulen et al. 2012). Therefore, the concept of reducing emissions through reducing food miles clearly has limits. The consumption of local food in an average American household yields a maximum reduction of 4-5% of the total greenhouse gas emissions related to food consumption. For fruits and vegetables this share is 11%, because the production phase is less emission intensive (Weber and Matthews 2008). For the UK, a recent life-cycle analysis of community agriculture on vacant land reported a reduction of only 0.4% of the total food-related emissions (Kulak et al. 2013). Reduced yields, additional inputs (e.g. containers or artificial soil) and reduced scale effects may even cause higher green-house gas emissions in UA than in the conventional supply systems (see also Kulak et al. 2013) . Thus, reducing transport by consuming local food does not *a priori* trigger a net greenhouse gas emission reduction in our food supply. It can reduce emissions at a local scale, with small-scale producers, and produce suitable for the local climate, soils and seasons (Edwards-Jones 2010; Kulak et al. 2013). The indication that UA potentially alters consumer diets towards low carbon foods means that UA may also have an indirect reduction effect on the household carbon footprint (Jones and Kammen 2011).

Additional regulating services: In organic agriculture, minimum soil disturbance, the use of compost and green manure, and the application of mulch and cover crops are principles adopted from conservation agriculture to maintain soil structure, fertility and biotic activity (e.g. Verbruggen et al. 2012). Crop protection is focused on avoiding pests, weeds and diseases, for instance by crop rotation, integrated pest management and the use of locally adapted and resistant races (see e.g. Sandhu et al. 2010). Organic waste flows are recycled as fertilizer (Rojas-Valencia et al. 2011). UA adhering to organic principles therefore has the potential to reduce indirect emissions (e.g. the emissions of fertilizer and pesticide manufacture) and improve regulating ecosystem services.

Also here, quantitative data is very scarce. In New York, 54 wild bee species (13% of the bee fauna recorded for NY State) persist in community gardens (Matteson et al. 2008) and in Chicago native bees were found to be present on urban green roofs (Tonietto et al. 2011) but not much is known about their pollination services. In Zurich, the extent of green infrastructure increased bee and hoverfly visits to flowering plants (Hennig and Ghazoul 2012) and in Stockholm

Table 2. Potential contribution of urban agriculture on provisioning, regulating and cultural services of urban ecosystems

Service	Small UA	Large UA*	Notes
Provisioning services			
Food	+	++	Size constraints limit yields; important at the local scale
Fiber	-	+/-	Green manure may have fibers but is preferably used to improve soil fertility
Fuel	+/-	+/-	Woody biomass is preferably recycled
Genetic resources	+	++	Small scale allows use of old or non-commercial varieties and land races
Biochemicals, medicines	+/-	+	Feasible but uncommon
Fresh water	-	--	Consumes water
Regulating services			
Air quality regulation	-	+/-	Limited and potential negative health effects
Climate regulation, local	-	+	Size constraints limit local climate regulation
Climate regulation, global	+/-	+/-	Avoided transportation expected to contribute to reduction of global emissions but effect is probably limited; indirect reductions of emissions via diet change expected
Water regulation	+	++	Increases infiltration, retention and transpiration; may control storm water
Erosion regulation	+	+	Cover prevents erosion
Water purification	+	++	Infiltration and retention prevents overspill from sewers, improves surface water quality
Waste treatment	+/-	+	Recycles organic waste flows as fertilizer
Human disease regulation	+/-	+/-	Long-term health risks not known
Pest regulation	+	+	Small-scale and avoidance of monocultures minimize incidence of pests
Pollination	++	++	Supports native pollinator communities
Cultural services			
Cultural	++	++	Reconnects consumers to food production
Social relations	++	+++	Improves urban social networks
Knowledge system	+	++	Conserves old gardening/farming methods
Aesthetic values	+++	++	Improves quality of urban life
Education/Recreation	++	++	Improves urban ecological structure

* Arbitrary size classes of UA types where pavement gardens or individual containers are typical examples of small UA and community gardens or CSA typical examples of large UA

pollinators were found in higher abundance in less formally managed allotment gardens compared to city parks (Andersson et al. 2007). In a study in northern Belgium that used container gardens in an urban environment, bumblebees (*Bombus spp.*) and solitary bees (*Anthidium spp.*) efficiently pollinated experimental plant populations (Verboven et al. 2012). In a similar study in Chicago, insect pollinator services were sufficient for native plants on urban green roofs although green roofs supported a smaller and less diverse pollinator community than ground level habitats (Ksiazek et al. 2012). Ants, arthropod predators and microbial communities are the major regulators of pest populations in urban soils and they can probably be harnessed to control insect pests affecting UA (Yadav et al. 2012; Gardiner et al. 2014). These studies suggest that, when integrated in the network of gardens and green space in the urban landscape (Goddard et al. 2010; Cameron et al. 2012), UA can contribute to the conservation of biodiversity and its regulating services in the urban ecosystem.

Cultural services of urban agriculture

The socio-cultural services of urban agriculture are difficult to quantify but most are related to improved quality of urban life. Community-based forms of UA improve the social interactions between citizens of different age, culture and social background (Galluzzi et al. 2010). The practice of growing food and gardening reconnects people with land and nature, releases stress in working people, and contributes to healthier diets, at least for some social groups (Kortright and Wakefield 2011; Douglas 2012). Because of the improved interaction between different age groups, UA and in particular community gardening, may also play an important role in transmitting knowledge systems between generations (Barthel et al. 2010; Galluzzi et al. 2010). The socio-cultural services of UA therefore extend by far the apparent aesthetic and recreational values typically associated to green in the city and appear to be more important than their agricultural function (Saldivar-Tanaka and Krasny 2004). The evaluation of 29 local food programme projects in the UK indeed showed that building community capacity (enhancing community cohesion, education, healthy diets, etc.) is at least as important as local food production for sustainable development of communities (Kirwan et al. 2013).

Conclusions

Our review indicates that there is general agreement that UA is important for local food production, especially in the south; that UA has a role in regulating green and blue water flows, organic waste flows and pollination; and that UA has important socio-cultural values, including an improved quality of city life. There is some evidence that UA may also improve human health because of dietary changes in certain social classes, but these are potentially confounded by environmental pollution in the city. However, quantitative evidence is very limited for all ecosystem services. The available data suggests that the overall food productivity and the total reductions in greenhouse gas emission are low at global or city-wide scale despite the fact that UA has potential strong effects on food security at the local scale. The current eagerness of industrialized cities to integrate UA into their food policies as an approach to become “climate neutral” or to rely on ecosystem services to become more resilient (Jansson 2013) calls for life cycle assessment studies that accurately quantify emission reductions and other urban ecosystem services of urban agriculture.

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Wouter M.J. Achten: writing: review and editing

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