The case for citizen science in urban agriculture research

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Abstract

In an uncertain future of climate change and constrained resources, urban agriculture is widely viewed as a sustainable and scalable approach to improving food security. While its social, health and wellbeing benefits are well documented, there is a major knowledge gap in terms of the financial accessibility of urban food production for all households. The implications are far-reaching: if urban agriculture is purely a middle-class discretionary activity, then it will play a limited role in improving food security on a city-wide scale. While community gardens are relatively well studied, research into the inputs and productivity of individual household food gardens presents profound practical challenges, notably the sheer number of geographically separated gardens, the enormous diversity of garden sizes and types, as well as highly variable cultivation and irrigation techniques. In this paper, we demonstrate that a citizen science approach offers a unique method to overcome many of these research challenges. We report on the Edible Gardens project in South Australia, a citizen science project developed to investigate the inputs (labour, costs and water use), and outputs (produce yields and value) of urban food gardens. Citizen science enables a large cohort of gardeners to measure these inputs and outputs and report on a wide variety of production methods over an extended period of time. We conclude that citizen science is an effective approach for future urban agriculture research.

Introduction

Although there has been a recent revival of interest and engagement in urban agriculture in the developed world (Matos & Batista, 2013; Schupp & Sharp, 2012; Wise, 2014), there remains concern over the lack of field-based quantitative data on the required inputs and productivity of urban food gardens (Pourias, Duchemin, & Aubry, 2015; Taylor & Lovell, 2013; Ward, Ward, Mantzioris, & Saint, 2014; Wise, 2014). In this paper, urban agriculture (UA) is defined as home, community, school and allotment gardens within urban areas, including the keeping of urban livestock such as poultry, fish and bees. UA has been found to enhance connection to place (Turner, 2011), connection to nature, and assist the mental and physical health of the people involved (Alaimo, Packnett, Miles, & Kruger, 2008; Balmer et al., 2005; Galhena, Freed, & Maredia, 2013). Those interested in the productivity of UA are concerned with whether or not it can help households to save money, grow more food on less land, produce highly nutritious food, improve self-sufficiency, or grow more food with less water (Algert, Baameur, & Renvall, 2014; Gerster-Bentaya, 2013; Ward & Symons, 2017; Ward, Ward, Mantzioris, et al., 2014). UA in developing regions of the world, such as parts of Africa, Asia and Latin America, is often guided by very different motivations and faces different challenges than UA in developed countries (Nugent, 2000; Petts, 2005; Van Veenhuizen & Danso, 2007). Consequently, the scope of this paper is UA in developed countries, as the research approach demonstrated here is most applicable to countries with similar UA to Australia. In this context, a citizen science project, "Edible Gardens" is presented, amid discussion of how it was developed to address practical UA research concerns.

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Research into the productivity of urban food gardens faces many practical challenges, notably: the sheer diversity of food gardens, their geographic spread across suburbs, towns and cities, and their low physical accessibility (Conway & Brannen, 2014; Kortright & Wakefield, 2011; Taylor & Lovell, 2013). Initial interest in the productivity and possible economic benefits of urban food gardens resulted in detailed studies on small numbers of purpose-built experimental gardens. Recent research has shifted more towards generalised studies on larger numbers of pre-existing food gardens. The broader applicability of past studies is limited due to the small number of gardens involved (Cleveland, Orum, & Ferguson, 1985; Pourias et al., 2015; Stall, 1979; Stephens, Carter, & Van Gundy, 1980; Utzinger & Connolly, 1978; Vitiello, Nairn, Grisso, & Swistak, 2010; Vitiello, Nairn, & Planning, 2009), short data collection periods (Conk, 2015; Gittleman, Jordan, & Brelsford, 2012; Stephens et al., 1980; Vitiello et al., 2010; Vitiello et al., 2009; Zainuddin & Mercer, 2014), and the difficulty of measuring relevant inputs such as labour, costs and water use.

Historically, urban food production has flourished during times of need, such as times of change, war, economic downturn or environmental concern (Gaynor, 2006; Gert, 1996; Kemp, 1977; Zilans et al., 2016). In major European and British cities, urban allotment gardens began appearing during the industrial revolution (Matos & Batista, 2013; Zilans et al., 2016). With such widespread rural-urban migration, housing was often severely overcrowded and shortages of fresh food were common. Originally, it was suggested that allotment space be provided to the urban poor to enable them to supplement both their fresh food supplies and reduced incomes (Barthel & Isendahl, 2013; Barthel, Parker, & Ernstson, 2013; Kemp, 1977; Kim, 2014; Matos & Batista, 2013). In Northern France in the late 1800's, the situation was so dire that as much as 50-90% of a household's weekly budget could be spent on food (Kim, 2014). Since the 1980's, however, urban food production in developed countries, such as Australia, New Zealand, the US, the UK, Europe and Canada, is now more commonly viewed as an expression of enjoyment, leisure, exercise and health, rather than a productive undertaking (Matos & Batista, 2013; Nugent, 2000; Petts, 2005). This view lies in direct contrast with developing countries, where UA persists as a major livelihood for many of the world's cities, for example, Nairobi, Cairo, Cuba, La Paz and Hubli-Dharwad (Nugent, 2000).

Putting aside for the moment the documented social, physical and wellbeing benefits of participating in UA, there is a practical need to establish whether the original purpose of encouraging urban food production (i.e. to help supplement the fresh food supplies and reduced incomes of the urban poor) is still accessible in modern urbanised areas. The implications are far-reaching: if UA is purely a middle-class discretionary activity, then it will play a limited role in improving food security on a city-wide scale. A recent report by the Australian Bureau of Statistics (ABS) (2015b) found that just under 25% of the Australian population depends upon government assistance for between 50-100% of their gross household income. Attempting to follow healthy food habits, such as those recommended by Australian standards, was found to be a serious fiscal challenge for welfare-dependant households (Kettings, Sinclair, & Voevodin, 2009). Indeed, 4% of the Australian population reported experiencing food insecurity, i.e., when a household runs out of food and cannot afford to buy more (ABS, 2015a). Participation in some forms of UA, such as community gardens, has been found to help reduce food insecurity (Carney et al., 2012; Kingsley & Townsend, 2006) and increase access to fruit and vegetables, especially in low-income areas (Armstrong, 2000; McCormack, Laska, Larson, & Story, 2010). However, it remains unclear whether it is feasible for households to save money by growing some of their own food, if all the relevant inputs are taken into account (Ward & Symons, 2017).

Citizen science is defined as "public participation in organised research efforts" (Louv, Fitzpatrick, Dickinson, & Bonney, 2012). Citizen science engages members of the public to assist in a range of activities, with data collection being the most common task (Catlin-Groves, 2012; Cooper, Dickinson, Phillips, & Bonney, 2007; Williams, Stafford, & Goodenough, 2014). It is suitable for large geographic scales and hard-to-access places, for example private land, homes and gardens (Cooper et al., 2007; Louv et al., 2012; Williams et al., 2014). In their study to quantify community garden crop yields, Gittleman et al. (2012) employed citizen science principles and techniques in their project's design, data collection methods and online infrastructure. Their 'citizen scientists' collected data on their own community garden sites. Arranging access for scientists to a large number of sites would have otherwise been both time consuming and costly (Toms & Newson, 2006; Williams et al., 2014). Citizen science is also capable of collecting large quantities of data over extended time periods (Bonney et al., 2009). Study results are typically presented to the citizens involved or made accessible for their use. Projects with greater levels of engagement provide ways for participating citizens to record and track their data, share it with others and even analyse it to draw their own conclusions (Louv et al., 2012; Wiggins & Crowston, 2011).

This paper reviews and critically evaluates past and recent research into the inputs and productivity of UA. The main challenges and issues of such research are discussed in depth. The second half of the paper demon-

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strates citizen science as a suitable approach to mitigate many of the inherent challenges of future urban agriculture research. We report on the Edible Gardens project in South Australia, a citizen science project developed to investigate the inputs (labour, costs and water use) and outputs (produce yields and value) of urban food gardens.

UA yield research

Research into quantifying the yields, economic benefits and required inputs of UA can be roughly divided into two timeframes. It was in the US in the 1970's that research initially began on the feasibility of urban home food gardens to save household money. Of five initial studies, four of them collected data from purpose-built demonstration gardens (Cleveland et al., 1985; Stall, 1979; Stephens et al., 1980; Utzinger & Connolly, 1978), while the fifth collected estimated survey data from pre-existing home vegetable patches of small farms (Gladwin & Butler, 1982). The inputs and outputs for a small number of gardens, such as labour, yield (with retail value calculated) and basic costs, were typically measured over a period of three to twelve months. All studies presented their results as a total average yield of kilograms per square metre (or pounds per square foot), with no differentiation between different crops. Two of these studies recorded high yields of more than 6 kg/m^2 (Stall, 1979; Utzinger & Connolly, 1978), while another two reported lower yields of between 1.2-2.7 kg/m^2 (Cleveland et al., 1985; Stephens et al., 1980). Gladwin and Butler (1982) did not calculate an average yield per square metre. Labour was recorded by all five studies, although only Stephens et al. (1980) reported net financial savings. Water use has often been overlooked in UA research. Utzinger and Connolly (1978) and Stephens et al. (1980) recorded water use merely as a cost. Cleveland et al. (1985) conducted the longest study, collecting data from two purpose-built gardens over 2.5 and 3 full years. This investigation remains the only field-based UA yield study to measure water use as an input (albeit from "experimental" gardens).

Research into the economic viability and productivity of UA gardens then experienced a lull until 2009. This is not to say that research into UA ceased entirely, rather that research during this time shifted its focus towards community gardens (Armstrong, 2000; Gert, 1996; Twiss et al., 2003), the relationship between urban food production and urban planning (Ellis & Sumberg, 1998; Lawson, 2004; Schmelzkopf, 1995), related health benefits (Brown & Jameton, 2000), and finally into the value of social, place-based and community-driven forms of alternative food supplies (DeLind, 2002; Moisio, 2004; Sage, 2003). In the intervening years, the cost of fresh water has risen considerably (Ward, Ward, Saint, & Mantzioris, 2014). The increased cost of required inputs may have an impact on the net value of urban food production.

Since 2009, there have been eight studies into the productivity of UA in modern urban environments. Of these eight studies, five of them were concerned purely with community-style gardens (Algert et al., 2014; Gittleman et al., 2012; Pourias et al., 2015; Vitiello et al., 2010; Vitiello et al., 2009), while the remaining three studies concentrated on home gardens (Codyre, Fraser, & Landman, 2014; Conk, 2015; Zainuddin & Mercer, 2014). All of these studies collected data only during their respective "growing seasons". For some, this was as short as three or four months (Algert et al., 2014; Conk, 2015; Vitiello et al., 2010; Vitiello et al., 2009; Zainuddin & Mercer, 2014), while the longest recorded growing season was eight months in Paris (Pourias et al., 2015). While Gittleman et al. (2012) did collect data from two growing seasons and Conk (2015) collected data from three growing seasons, none of these more recent studies spanned an entire year. With regards to yield, two studies reported high yields of between 5-7 kg/m^2 (Gittleman et al., 2012; Vitiello et al., 2009), three studies reported intermediate yields of between 2-4 kg/m^2 (Algert et al., 2014; Conk, 2015; Vitiello et al., 2010), and three studies reported lower yields of between 0.35-1.7kg/m^2 (Codyre et al., 2014; Pourias et al., 2015; Zainuddin & Mercer, 2014). Again, results were presented as total average yield per square metre. High documented variability among individual garden yields was common (Algert et al., 2014; Codyre et al., 2014; Conk, 2015; Pourias et al., 2015; Vitiello et al., 2009; Zainuddin & Mercer, 2014). All but one study (Zainuddin & Mercer, 2014) calculated the retail value of the crops harvested. Measurement of related inputs such as labour, costs and water use was uncommon. Codyre et al. (2014) included labour and costs as part of their research, while the other seven studies did not. Water use was not measured at all.

Over time, research into the productivity of UA has transitioned from detailed studies on a small number of purpose-built experimental gardens, to more generalised studies on a larger number of pre-existing food gardens. The measurement of related inputs remains challenging, particularly as the number of gardens involved increases. In order to study UA productivity effectively, different UA practices, approaches and crops must be clearly defined. This provides a clearer context for the different yields and input or resource requirements of various approaches, thus allowing for enhanced analysis and comparison.

Issues with past research into urban agriculture productivity

Home food gardens have been considerably overlooked with regard to research, interest and support (Conway & Brannen, 2014; Taylor & Lovell, 2013; Zainuddin & Mercer, 2014). This is particularly true in comparison to community gardens (Golden, 2013; Gray, Guzman, Glowa, & Drevno, 2014; Kortright & Wakefield, 2011). This disparity is perceptible in the public government acknowledgement and support in Adelaide, South Australia. Currently, the 30 Year Plan for Greater Metropolitan Adelaide supports community gardens for their contribution to social interaction and physical wellbeing (Government of South Australia 2010, Chapter D: Policies and Targets; Health and Wellbeing – Policy 2, pg. 101). No mention is made of either home food gardens, or of the capacity of urban food gardens to actually produce food.

Explanations for the scarcity of home food garden studies include: the enormous diversity of food gardens, the difficulty in allowing for the variety of growing styles and methods in research, and the low visibility and physical accessibility of home food gardens (Conway & Brannen, 2014; Kortright & Wakefield, 2011; Taylor & Lovell, 2013). The six main issues with past UA yield research identified by this review include: using experimental gardens instead of pre-existing gardens, using small data sets or commercial yield rates for theoretical extrapolations of potential UA yields, the lack of water use data, how to value time invested as labour, and finally, what constitutes reasonable productivity and nutritional contributions.

1. Monitoring experimental food gardens rather than pre-existing food gardens

Collecting data from purpose-built experimental food gardens is likely to represent "best case scenarios" as they are designed, planted, tended and monitored by scientists. Such experimental gardens differ from the widely varying range of pre-existing home and community gardens, which are designed, built and tended to by regular citizens (with their own range of knowledge and experience). Another consideration is that the majority of studies based on experimental gardens only collected data on one production type or gardening approach, for example "in-ground beds" or "organic gardening". In their study on home food gardens in Melbourne, Zainuddin and Mercer (2014) found that most of their participants made use of more than one gardening approach. Different approaches may have individual merits or disadvantages, which in turn could influence the various efficiencies and productivity of food gardens.

2. Theoretical extrapolations of UA yields

Due to the lack of rigorous large-scale input and yield data, there has been a tendency to base theoretical extrapolations of potential large-scale UA yields on either relatively small data sets (Vitiello et al., 2010; Vitiello et al., 2009) or commercial yield rates and input requirements (Garnett, 2000; Ward & Symons, 2017). Estimating potential yields, particularly for city-wide predictions, is considered both difficult and generally unreliable due to the number of variables involved (Ackerman, 2011). One recent study by Ward and Symons (2017) showed that crop selection could be theoretically optimised to design "best case" food gardens, and that such optimised gardens could potentially deliver non-trivial household savings, even accounting for the high price of water and dry climate of a city such as Adelaide, South Australia. However, a lack of UA input and yield data means that their study relied on applying commercial yields and theoretical crop water use requirements. For the proposed benefits to be achieved in practice, real-world data must be obtained to inform proper garden design and implementation.

3. Water as an input

Very little is known about the current water consumption of UA (Ward & Symons, 2017; Ward, Ward, Saint, et al., 2014). As noted earlier, Cleveland et al. (1985) remains the only field-based UA input and yield study to measure water use. Water was their single largest expense—almost 30% of the total costs for each garden—while watering by hand took approximately 50% of the total hours spent. Not only is fresh water a valuable and sometimes scarce resource, but in many parts of the world, the price of fresh water is rising. The productive capacity of UA must therefore take into account the amount and price of the water required to produce food. If the cost and/or availability of water is found to be a barrier to cost-effectiveness in UA, then future research can begin to look into possible water saving techniques (e.g. drip or precision irrigation, the use of timers or alternative water sources) or alternative production methods for greater water use efficiency.

4. Labour as an input

It is difficult to measure the value of labour. The hours spent producing food can be dismissed if the activity is perceived as a discretionary leisure activity, or as valuable purely for its social, health or wellbeing benefits. Such an approach is acceptable, providing the household involved is not attempting or expecting to save money. Of the previous studies which measured labour as an input, five of them found that any small financial savings made were negated once the minimum wage rate of the time was applied (Cleveland et al., 1985; Codyre et al., 2014; Gladwin & Butler, 1982; Stall, 1979; Utzinger & Connol-

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ly, 1978). The most recent of these studies, by Codyre et al. (2014), even found that their average gardener was paying 39% more by producing their own fruits and vegetables even before apply a labour wage, simply due to the recurring costs involved. Stephens et al. (1980) was the only study to report net financial savings once their minimum labour wage of US$3.10/hour was applied. No recent study has yet reported net financial savings once applying a minimum wage to the time invested in urban food production. Alternatively, for urban farmers in developing regions of the globe, their labour is not strictly measureable by the categories of industrial wage labour. For example, 68% of urban farmers in Carapongo, Peru live on less than US$2 per person per day (Villavicencio, 2008). Thus, it is once again important for researchers to define the kind of UA which they are researching to ensure that the applicability of their work is clear.

With regard to the length of UA data collection, none of the more recent aforementioned studies collected data on an entire year, or longer. This is understandable due to the substantial investment in resources to conduct long-term in-field research. Consequently, short-term literature on UA cannot take into account the production of early or late crops, or how additional time to maintain and prepare food gardens is often required throughout the other months of the year. Time spent could also be profiled according to each related food growing activity, such as weeding, planting or watering. Unfortunately, few studies have the resources to record labour to this level of detail, yet it could be a comprehensive way to compare the labour efficiency of different garden setups.

5. Productivity and nutrition

The yield rate required to make UA financially or nutritionally worthwhile for individuals and households in modern urbanised areas is highly subjective. Some high yields have been documented and may be achievable under certain circumstances (Gittleman et al., 2012; Nugent, 2000; Vitiello et al., 2009). However, opposing research remains sceptical that the estimated UA yields can be attained (Conway & Brannen, 2014; Ward, Ward, Mantzioris, et al., 2014). Recorded yields from past UA research ranged from as low as 0.35 kg/m^2 (Zainuddin & Mercer, 2014) to as high as 6.85 kg/m^2 (Utzinger & Connolly, 1978), typically with high levels of variability among gardens (Algert et al., 2014; Codyre et al., 2014; Conk, 2015; Pourias et al., 2015; Vitiello et al., 2009; Zainuddin & Mercer, 2014). This lack of differentiation between individual crop yields is problematic and doesn't allow for accurate comparisons among various crops, production methods or gardening approaches. For example, a yield of 1 kg of potatoes per square metre is very different from 1 kg of eggs per square metre with regards to nutrition (e.g. energy or protein), retail value, and required inputs (e.g. time, money and water). It is also possible for gardeners to utilise different gardening approaches in order to enhance their garden's productivity. Five such approaches which are relatively well known include: Continuous Productive Urban Landscapes (CPULs), Grow Biointensive, SPIN farming (small plot intensive), Permaculture and high-tech urban horticulture. Currently there is a lack of scientific studies comparing different gardening approaches in terms of their productivity and efficiency, which would shed light on whether any of these approaches are reliable in practice.

Another aspect of UA which may influence productivity is the gardener's level of experience. The majority of the people growing food in the original allotment gardens had the benefit of agricultural experience, having recently moved from rural areas (Barthel et al., 2013). By comparison, there is currently concern over the disparity in food growing knowledge and skills between single generations (Barthel & Isendahl, 2013), in addition to discussions about the loss of skilled labour in traditional farming (Millar & Roots, 2012). Indeed, the owners of a small Adelaide-based urban farm, Wagtail Urban Farm, recently told the authors of how they had to travel interstate to find someone with the skills and knowledge of small-scale continuous production to teach them. UA input and productivity studies have not collected sufficient data to analyse the relationship between gardening experience and productivity, with the exception of Codyre et al. (2014). By comparing their 50 home food gardens, gardeners with more than seven years' experience were found to be statistically more productive. In the Californian-based study by Algert et al. (2014), gardeners with less than four years of gardening experience were intentionally disregarded.

Past research has advocated the benefit of increasing people's access to fresh fruit and vegetables (Armstrong, 2000; McCormack et al., 2010), and how best to supplement people's fruit, vegetable and protein needs (Ward, Ward, Mantzioris, et al., 2014). Even in places where the need is greater, such as in some developing countries, urban food gardens are still commonly only a supplementary food source (Nugent, 2000). One long-running program in the US called SNAP (Supplemental Nutrition Assistance Program), provides more than 46 million low-income households with credits to purchase fresh produce (Simon, 2012). These credits can also be used to obtain seeds and food plants; however, this is not well known, and there is currently no monitoring of how many SNAP households do purchase seeds or food plants, or how successful they may be in producing food (Simon, 2012). There is therefore a need to collect additional data not only on the physical inputs and yields of UA, but also on the related motivations and experience of gardeners who choose to grow their own food.

Citizen science

Home food gardens remain challenging to study due to their sheer diversity, geographic spread, low visibility and physical accessibility (Conway & Brannen, 2014; Kortright & Wakefield, 2011; Taylor & Lovell, 2013). The main issues of past research into the inputs and productivity of UA include: the need to collect data on pre-existing food gardens; the tendency to omit vital inputs such as labour, water use and costs; and the need for longer studies on a greater number and variety of urban food gardens. One research approach which can overcome many of these challenges is citizen science. Indeed, it has already been employed for UA research by Conk (2015) and Gittleman et al. (2012).

There are some challenges of using a citizen science approach in this context. The first is that public participants are untrained; therefore, they may require training or, at the very least, need to be provided with explicit and tested protocols to follow (Bonney et al., 2009). Participant-collected data may also be inconsistent or skewed (i.e. measured or recorded incorrectly) and it is best to ensure verification by suitably trained people (Bonney et al., 2009; Dickinson, Zuckerberg, & Bonter, 2010; Louv et al., 2012). Regardless, the people involved in citizen science projects can include the untrained general public, or can target special interest groups (e.g. engaging experienced birdwatchers for ornithology research projects) (Catlin-Groves, 2012). The second challenge is that, for long-term projects, it can be difficult to continuously engage large numbers of participants over time (Louv et al., 2012). As a demonstration of the suitability of citizen science for UA research, the following section outlines the design of an Adelaide-based citizen science project launched in September 2016.

The Edible Gardens project

The Edible Gardens project was developed to investigate the inputs (labour, costs and water use), and outputs (produce yields and value) of urban food gardens in South Australia. This is a project of the Discovery Circle - a citizen science initiative of the University of South Australia. The project team (all authors of this paper) was carefully comprised of a citizen science specialist (PR), an environmental water engineer (JW) and a PhD candidate specialising in UA (GP).

The Edible Gardens project targeted urban gardeners over the age of 18 who grew food in home, community or school gardens in South Australia. There was no required skill-level for participation in the project; beginner gardeners were equally as welcome as gardeners with many years of experience. The gardens involved included a wide variety of fruit, vegetable and herb gardens, and even those keeping urban livestock such as chickens, bees and fish. The project was designed around two main phases: an online survey and an in-field garden data collection by selected participants. Due to the current enthusiasm for learning about "growing your own" (Pourias et al., 2015), recruiting gardeners for this project was expected to be relatively straightforward. The project was promoted via the Discovery Circle website, newsletter and Facebook page. Other print materials and press releases were circulated via local and state-wide channels, particularly by the project funders (see acknowledgements).

Phase 1 of the project involved creating an online survey (via Survey Monkey), which asked respondents about their motivations, any challenges, their years of experience and from where they learned to grow food. They were also asked to describe their food gardens (size, production method, gardening approaches, water sources and irrigation methods), and estimate their typical yields, labour, expenses and water use. Thus far, over 400 gardeners have responded to the online survey.

Phase 2 involved selecting participants to collect data on their own food gardens. This phase required the development of a number of project protocols and resources, including data collection toolkits and customised online infrastructure. A web developer was hired to create the online infrastructure, including a database for data storage (hosted by Microsoft Azure) plus a web interface (embedded in the Discovery Circle website). This infrastructure allows each participating garden to have an online description and photograph, linked to data entry and data visualisation pages. It was designed so that, as participants enter data, graphs of their data are automatically generated to display preliminary results for each individual garden. These online graphics can be used to compare food production areas within gardens (e.g. between two different garden beds) and between gardens (i.e. participants can access data from other participants and compare their productivity, water use, and labour, all displayed on a per square metre basis for easy comparison). **Figure 1** is an example of the labour recorded in four different growing areas belonging to one garden.

Approximately 70 of the survey respondents were selected and proceeded to register their gardens for Phase 2. During registration, participants first described their garden and gave it a name. They then entered the number, size and location of the "growing areas" they wished

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Figure 2: Three gardens and measurement (Photo Credit: Georgia Pollard)

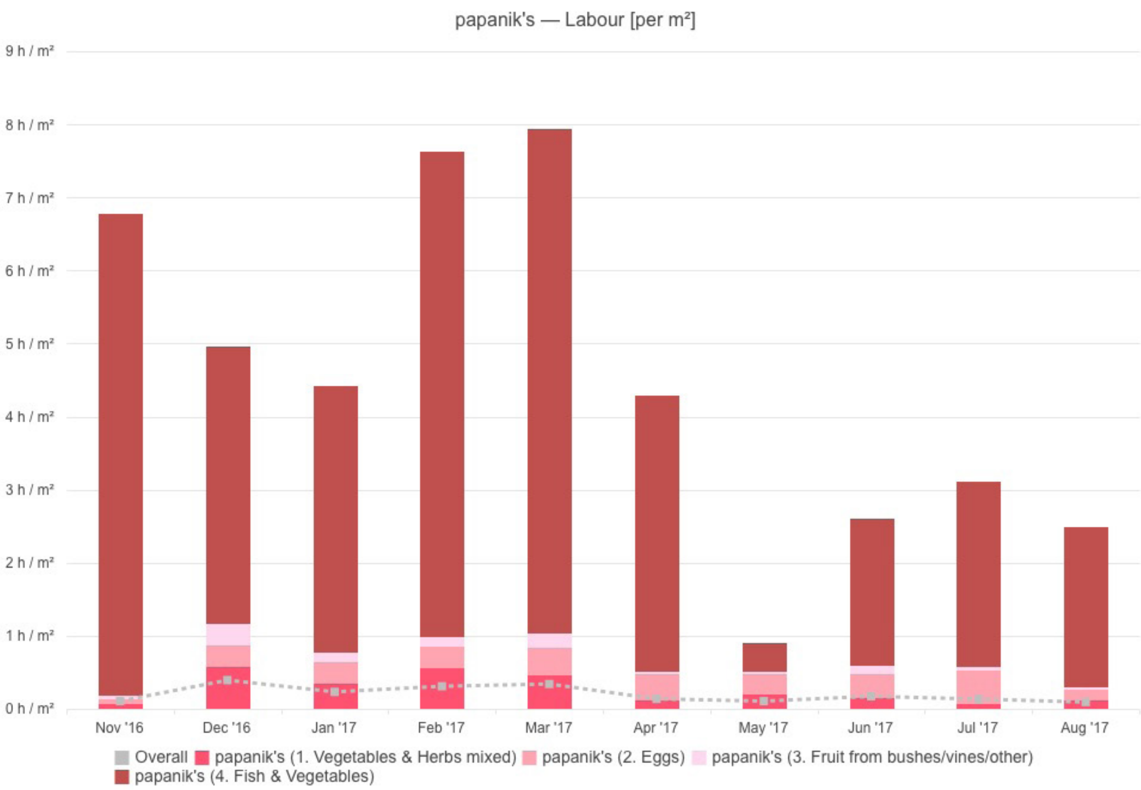

Figure 2: Labour invested per square metre for four growing areas in one garden

to collect data on. Growing areas were defined by their production method and typical crop (e.g. 1st area: in-ground vegetable patch; 2nd area: fruit trees in pots; and 3rd area: chickens in a chicken run). Participants also entered information on the water source (e.g. mains, rain, bore or grey water), irrigation system and tap type for their growing areas. These details were important to ensure that each participant's data collection toolkit was customised to best suit his or her garden. The data sheets and instructions were adapted with permission from the Harvest Count section of the Farming Concrete Data Collection Toolkit created by Gittleman et al. (2012). Sections were added to record additional data on water use, time spent and costs. The Edible Gardens toolkits were posted as a package containing data sheets, a spring balance to weigh harvests, one or more water meters (depending on each irrigation setup), and explicit instructions complete with images and examples, as recommended by Bonney et al. (2009).

Participants collected data on three types of inputs: related expenses, time spent on specific garden activities and water use. They also collected data on harvested yields, and recorded any produce shared with others outside of their household. This is currently the widest range of inputs recorded on non-experimental food gardens. Participants were able to choose how long they wished to collect data. Some collected data for three months, while others have completed ten months thus far. In order to keep participants engaged with collecting and entering their data online, emails were sent every two months with updates on how the project was progressing, the number of people involved, what sort of data was being collected and reminders to please enter their data monthly.

With regard to the data collected and stored in the online database, it was expected that it would need verification and cleaning before it could be analysed by the project team (Bonney et al., 2009; Dickinson et al., 2010; Louv et al., 2012). Although the majority of the Edible Gardens participants entered clean data, a few did have issues. Occasionally, yields were entered as grams rather than kilograms (e.g. 900 kg of broccoli instead of 0.9 kg of broccoli from a 6m2 growing area). Such mistakes are relatively easy to spot and did not require too much time to correct. One recurring issue was partly due to the configuration of the data entry webpage. Participants who kept chickens often entered the quantity of eggs collected (e.g. 3 or 4) into the "Yield (kg)" column, resulting in a yield calculation issue. This particular mistake required some changes to the structure of the underlying database.

A fundamental component of citizen science is the reciprocal relationship with the citizens who contribute to the project (Roetman, 2013). Without citizens contributing their valuable time and effort, the Edible Gardens project could not be so detailed or so large-scale. Therefore, providing reciprocal benefits was an important part of the project design. While collecting garden data, participants were able to download their raw data, while also visualising and interacting with the preliminary data displayed in their results charts (**Figure 2**). These charts could be downloaded, emailed or shared on social media. Once data collection is complete, each participant will receive a personalised report of their garden's results. In addition to summarising their total inputs (i.e. labour distribution, costs and water use) and yields, the report will also calculate the estimated retail and nutritional value of the crops they harvested. Finally, the overall project results and raw data will be made publically available and published as open-access research articles. This acknowledgement of the citizens' contribution is necessary (Droege, 2007; Roy et al., 2012; Silvertown, 2009), and can assist in greater recruitment and retention of citizen volunteers (Graham, Henderson, & Schloss, 2011).

Conclusion

There is uncertainty as to whether UA, as currently practiced, can realistically improve food security at the household scale in modern urbanised areas. Further research to evaluate the full inputs and productivity of urban agriculture for a range of production methods, gardening approaches, climates and locations is necessary. Research into the inputs and productivity of UA – especially on the individual household scale – faces a number of practical challenges, emanating from the dispersed and disconnected nature of the practitioners and the wide variety of skills and techniques being employed.

We contend that the challenges above can be overcome by utilising a citizen science approach, as implemented by the Edible Gardens project, to engage the urban food producers of South Australia in collecting quantitative data on their own food gardens. Custom online infrastructure allows the project to be promoted and data to be captured, stored and visualised in a timely and efficient manner. The online infrastructure includes descriptions of registered gardens, a data entry portal, and automatically-generated visualisations of preliminary results. This setup also allows participants to interact with each other (and the project) across a wide geographic area.

As part of the reciprocal relationship with the citizens who contribute to the project, participants can access their raw data and view their preliminary garden results and interactive charts. Personalised final reports will also provide participants with a detailed overview of their results, including their inputs (i.e. labour, costs and water use), yields, and the estimated retail and nutritional value of their recorded harvests. This will inform further re-

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search (via a post-participation survey) to determine the impact of the project (specifically, the act of quantifying inputs and yields) on their own attitudes and practices towards food gardening.

Citizen science facilitates the combined collection of quantitative and qualitative data by a large number of UA participants relating to the motivations for practising UA, as well as the physical inputs and outputs of food gardens. The outcomes of this shared approach will be to provide essential insights into the sustainability, scalability and accessibility of this fascinating form of food production.

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Conflict of Interests

The authors hereby declare that there are no conflicts of interests.

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