Different Kinds of Worth: A Practical Investigation into the Productivity, Resource Efficiency and Social Value of Urban Agriculture



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Abstract

There is a collective anticipation that urban agriculture (UA) will contribute to more environmentally sustainable cities and urban areas. What remains unclear, however, is how reliable, substantial or meaningful that contribution will be; will the inclusion of UA in this collective vision add a net savings or a net cost? There is a lack of empirical research into the practicalities of UA, particularly on the productivity and resource efficiency of domestic food gardens and the social value of gardening activities. Without such research, there can be no evidence-based decision making to improve or upscale UA and its contribution to urban food security. This thesis investigates the productivity, resource efficiency and social value of urban food gardens in the Australian state of South Australia.

To mitigate many of the challenges of researching UA, a citizen science approach was utilised to develop and conduct a state-wide project called *Edible Gardens*. This project ran from late 2016 until mid-2018. Edible Gardens was open to home, school and community gardeners involved in all kinds of urban food production. The first phase of the project was an in-depth online survey, for which 402 respondents answered detailed questions on their garden setups, motivations and challenges, estimates of resource use, and personal and social insights into their food gardening experiences. The second phase of the project involved selecting participants (citizen scientists) to collect data in their own food gardens. Measured inputs included all irrigation (mains, rainwater, bore or greywater), plus all expenses and time spent on garden-related activities. Measured outputs included harvested crop weights and food shared with others. Data on the retail value and nutritional content of the food produced were collected separately. A substantial online web-interface was created to promote and support the project.

The research in this thesis makes a significant contribution in three key areas. Firstly, the survey data provided a detailed insight into the incredible diversity of garden setups, garden inputs and the gardeners themselves. Urban food gardens are complex combinations of cultivation techniques, gardening approaches, crop choices, water sources, irrigations methods, motivations, challenges and outcomes. The survey also

collected data on gardeners' values and areas of potential social connection, including food preservation, learning sources and food distribution practices. A difference was found between the 'subtle sociability' of home gardeners and the 'overt sociability' of community gardeners. Secondly, a broad range of input and output data was collected on 92 garden areas within 34 home food gardens. The EG gardens produced a wide variety of fruits, herbs, vegetables and animal products from almost a dozen different cultivation techniques. While the quantitative input and output results were typically highly variable, enough exemplar gardens returned results comparable to commercial and theoretical figures to suggest some potential for smaller, more intensive food gardens. Even when considering ongoing costs, a high percentage of the EG gardens (79%) were calculated to save more than AUS$250 per year. Indeed, the majority (65%) of the EG gardens were calculated to overcome both their setup and ongoing costs to break even in five or less years. And finally, this research demonstrated a rigorous method to study and collect data on existing urban food gardens. New research methodology, measurement methods, units of comparable values, garden area categories and water use efficiency equations were developed and applied.

This research developed a deeper understanding of the productivity, resource efficiency (including water use efficiency and financial sustainability) and social value of urban food gardens, particularly home food gardens. These data form a baseline dataset, which will be available open-source for external use, analysis, comparisons and theoretical modelling. The methods demonstrated in this thesis provide practical support and guidance for the expansion of future UA research, enabling the collection of more consistent and comparable data on larger numbers of existing urban food gardens. As the dominant form of urban agriculture in Australia, the diverse stock of existing home food gardens represents the greatest potential influence on our collective future urban food security.

Declaration

This thesis presents work carried out by myself and does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text; and all substantive contributions by others to the work presented, including jointly authored publications, are clearly acknowledged.

Georgia Pollard December 2018



"Alone we can do so little,
together we can do so much."

- **Helen Keller**

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This has been an ultimately surprising journey. I wasn't quite sure where this was all going when I began my research, but I am sure I didn't expect to enjoy it so thoroughly or to have so much interaction with others along the way. This research has turned out bigger, more complex, more fascinating and containing *way* more data than I ever thought possible. And I want to thank everyone who has helped me along the way.

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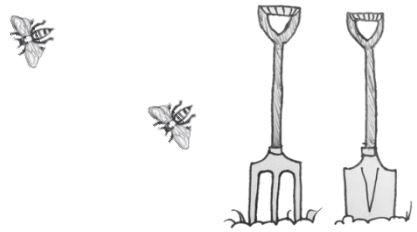

1 Introduction

Contextual Statement

This research contributes to a more complete understanding of the productivity, resource efficiency and social value of urban agriculture. Results are presented from the Edible Gardens Project, a two-year citizen science project designed to engage urban food gardeners across the Australian state of South Australia to collect and contribute a wide variety of data on their own food gardens.

Urban agriculture is distinguishable from traditional agriculture by its connections to urban social, economic and ecological systems (Balmer et al. 2005; Mougeot 2000). Opitz et al. (2016) advocate for further differentiation between urban agriculture, as a provider of mainly household level food, and peri-urban agriculture which can produce and distribute increased quantities of food. For the purposes of this research, however, urban agriculture (UA) is defined simply as any form of food production (including the keeping of livestock), occurring within the urban or peri-urban (fringe) areas of a suburb, town or city. It encompasses everything from a few pots of herbs on a windowsill, to home gardens, community gardens, public orchards, school gardens, allotments and all the way through to large urban farms. UA is not defined by size, crops grown, placement in the urban landscape, whether outside, indoors or on rooftops, or by the intended use of the food (whether for home, personal, or public consumption, for commercial sale or for any combination of the two). UA is inherently diverse and can blur indistinguishably into the surrounding agricultural landscapes.

This thesis contributes significantly to the field of UA research by systematically identifying and addressing practical aspects of the productivity, resource efficiency

and social value of UA, with a particular focus on home food gardens which, until now, have remained largely overlooked.

A Brief History of UA

Historically, UA 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 et al. 2013a; 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 et al. 2013a; Barthel et al. 2013b; Kemp 1977; Kim 2014; Matos et al. 2013a). 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). War has also been a strong motivator of increased urban food production (Zilans et al. 2016). During the first and second World Wars, citizens were encouraged to grow their own fresh produce to supplement emergency food supplies. The increase in food gardening during this time was remarkable. In Germany, the number of allotment gardens grew from 450,000 in the early 1930s to approximately 800,000 by 1949 after World War 2 (Gert 1996). Then in the 1960s and 1970s, concern for the environment, interest in self-sufficiency and spikes in food prices fuelled yet another swell of "growing your own" (Gaynor 2006; Matos et al. 2013b).

Since the 1980s, however, UA in developed countries, such as Australia, New Zealand, the US, the UK, Canada and parts of Europe, is now more commonly viewed as an expression of enjoyment, leisure, exercise and health, rather than as a necessity-driven productive undertaking (Matos et al. 2013a; Nugent 2000; Petts 2005). Some examples of popular UA initiatives include allotment gardens in London (Federation of City Farms & Community Gardens 2018; Garnett 2000), Schrebergärten and community gardens in Germany (Anstiftung Foundation 2018), widespread home, community and teaching gardens in Quebec, Canada (Laboratory on Urban Agriculture (AU / LAB) 2018) and the Stephanie Alexander Kitchen Garden Program in Australia (Stephanie

Alexander Kitchen Garden Foundation 2014). This view of UA differs somewhat from that in developing countries, where UA persists as a major livelihood for many of the world's cities, such as Nairobi, Cairo, Cuba, La Paz and Hubli-Dharwad (Nugent 2000). UA in developing countries is often less hampered by restrictions from urban planning, policy and legislation, local government by-laws and formal issues of health and safety – although these challenges are appearing as their cities seek to 'modernise'. In both developed and developing countries, there is concern over the absence of urban food planning and the lack of leadership by urban planners and municipal councils to facilitate UA (Davidson et al. 2014; Morgan 2009; Pollard et al. 2017; Thornton 2017). This lack of cohesive urban food planning is also apparent in Australia, where the link between land-use planning and food security is little understood (Budge et al. 2009; Caldwell et al. 2011; Davidson et al. 2014).

Introducing UA in South Australia

The geographical focus of this thesis is South Australia (Figure 1). Before the state of South Australia was founded and settled by British colonists in 1836, the Aboriginal Kaurna people occupied for thousands of years the land now known as the Adelaide Plains. The Kaurna people were the custodians of an intricate network of ecosystems – including a myriad of plants used for food, infrastructure and as temporal 'clocks' (Daniels et al. 2005). The newly arrived colonists found the soils and climate of the plains and hills around the chosen site of the capital city of Adelaide to be suitable for growing a wide variety of European crops. By the 1860s, the existing gardening practices of the established British were expanded by early German and Chinese settlers (Daniels et al. 2005). Throughout history, immigrants to Australia have helped contribute and celebrate different forms of UA by growing, sharing and cooking home grown (and market garden) produce, and by exhibiting a willingness to make use of any available space – including highly visible space such as front yards (Gaynor 2006).

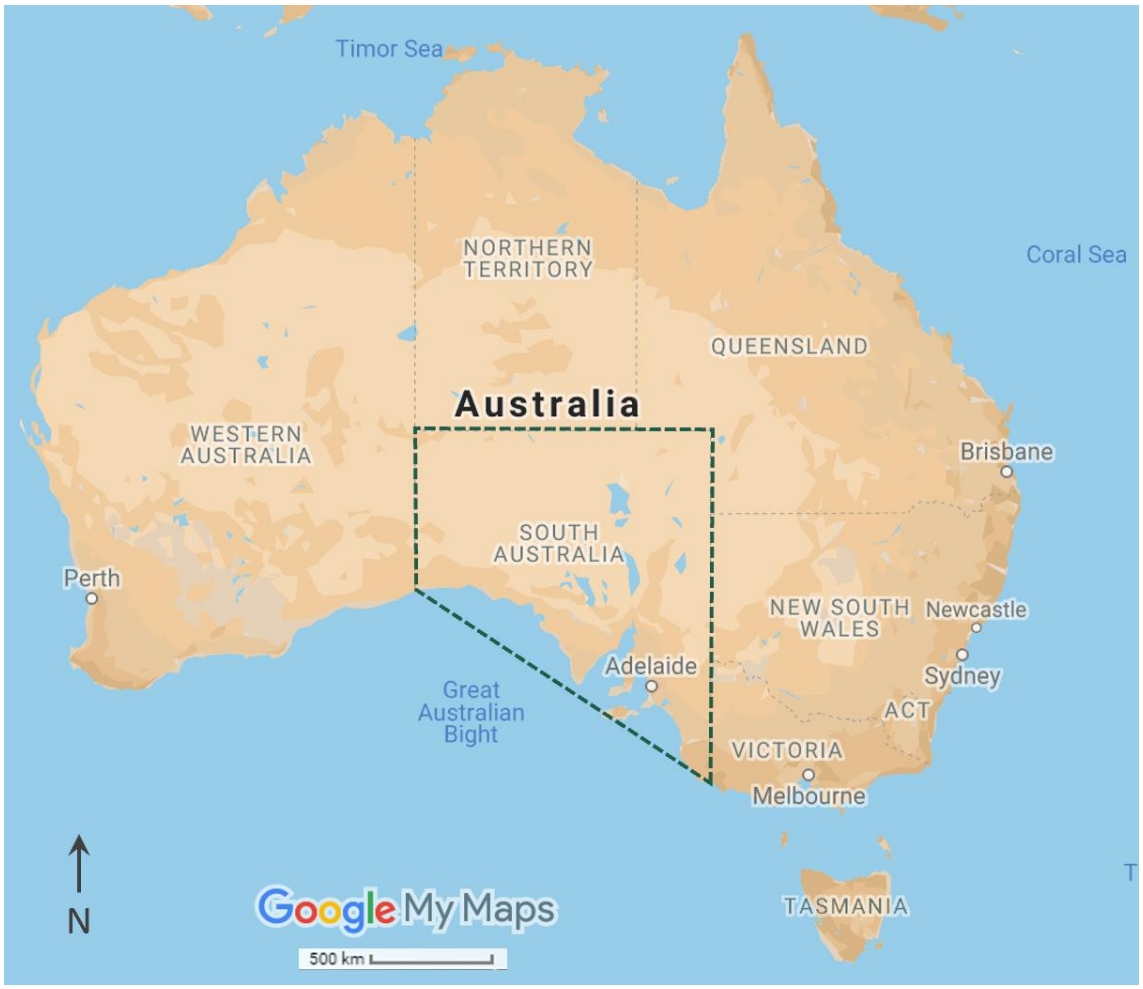

Figure 1: A map of Australia, with the state of South Australia outlined and the capital city of Adelaide pinpointed. Map from GoogleMyMaps (2019). The capital city of South Australia is Adelaide, which has a latitude of -34.921230 and a longtitude of 138.599503.

There have been three major Australian based surveys on UA relevant to South Australia. The first was conducted in Adelaide in 1973 by Halkett (1976). Of the households surveyed (n = 430), 48% grew fruit, 40% grew vegetables, 10% produced eggs and 7% grew nuts – these categories were not mutually exclusive. The second survey into home food production was conducted in 1992 by the Australian Bureau of Statistics (ABS). The households surveyed were asked about their country of origin. Of the households producing vegetables at the time, 71% were Australian, 10% were British & Irish, 4% were Italian, 2% were Greek, the Dutch, German and New Zealander were all 1% and the Vietnamese, Polish and "Other" made up less than 1% (Australian Bureau of Statistics (ABS) 1992). The third and most recent survey on UA was published by Wise (2014). The report found South Australian and Tasmanian

households to be those most likely (both 59%) to produce some of their own food – slightly higher than the Australian average of 52% (Wise 2014). Together, these three surveys demonstrate that although the popularity of UA in Australia has varied over the decades, it is also an activity that has persisted, and which continues to capture people's attention and devotion.

The state of South Australia was selected as a valuable study site for this research due to the high level of engagement in UA, the state's relationship with water, the recent government interest in health and wellbeing and the increase in state-based UA initiatives. Of the 59% of South Australian population currently engaged in producing some of their own food, 99% do so at home (Wise 2014). The remaining 1% reported growing food at a community garden (Wise 2014), but it is worth noting that there are 50 community gardens registered across the state (Australian City Farms & Community Gardens Network 2014).

With regards to water, a critical resource for UA, South Australia is known for its mostly arid and semi-arid climates, dependency on multiple water supplies and history of recycled water schemes (Marks 2010). As residents of a dry state, South Australians have been found to use 20% less water per capita than the average Australian (Australian Bureau of Statistics (ABS) 2015a).

From a health and wellbeing perspective, both the South Australian Department of Environment and South Australian Department of Health recently collaborated on a joint 'Healthy Parks, Healthy People' initiative to encourage people to get out in nature more – including into their gardens (Government of South Australia 2016). A variety of UA initiatives have also been founded in South Australia, including 'Grow Free' and 'Ripe Near Me'. Grow Free is a network of carts placed in public places across South Australia, where people can leave fresh produce, seeds and seedlings to give away freely to others (Barker 2018). As of April 2018, there were 137 Grow Free carts listed across South Australia (Barker 2018). Ripe Near Me was founded in 2012 by two Adelaide based 'foodies' (people with a particular interest in food) (Martin et al. 2018). They wanted to create a website to help people connect, find, grow, share and sell fresh local produce. The site hosts a map covered in different markers pin-pointing the

locations and ripeness of different foods. Anyone can register to post online markers of produce they have grown themselves, or even produce they have observed growing in other locations such as public spaces (Martin et al. 2018).

The Potential of UA

In visions of the future, UA has long been considered an integral part of the 'sustainable city'. It is anticipated that UA will contribute to food security, city resilience, conservation of resources, recycling of urban wastes, and that urban planning could even one day help transform our cities into farms (Burton et al. 2013; Deelstra et al. 2000; Farrell 2017; Pearson et al. 2010; Pires 2013; Smit et al. 1992). Modern food challenges expected to shape the future of global food security include the sharp rise in food insecurity, climate change impacts, land conflicts, and the acknowledgment of food as an issue of national security. These challenges have been collectively termed the 'New Food Equation' by Morgan et al. (2010). Observations by Millar et al. (2012) noted the uncertainty of Australia's long-term food security, namely due to issues with water sourcing, climate change impacts, loss of agricultural land, and a lack of succession of farmers and farming families. Regardless of the forms UA may take in the future, a valid question remains, "If UA is intended as an integral part of our collective expectation for the future, will it contribute as a net savings or a net cost?" If UA does not provide a net saving to food costs, then commercial and semi-commercial forms may rely on subsidies, perpetual fundraising or, as previously documented, a large contribution from volunteer labour (Biewener 2016; Goodman 2011; Kaufman et al. 2000; Laidlaw 2013). The three components of the potential contribution of UA to a sustainable future include home UA, community and educational UA, and commercial UA (Figure 2). Each of these components are discussed in further detail below.

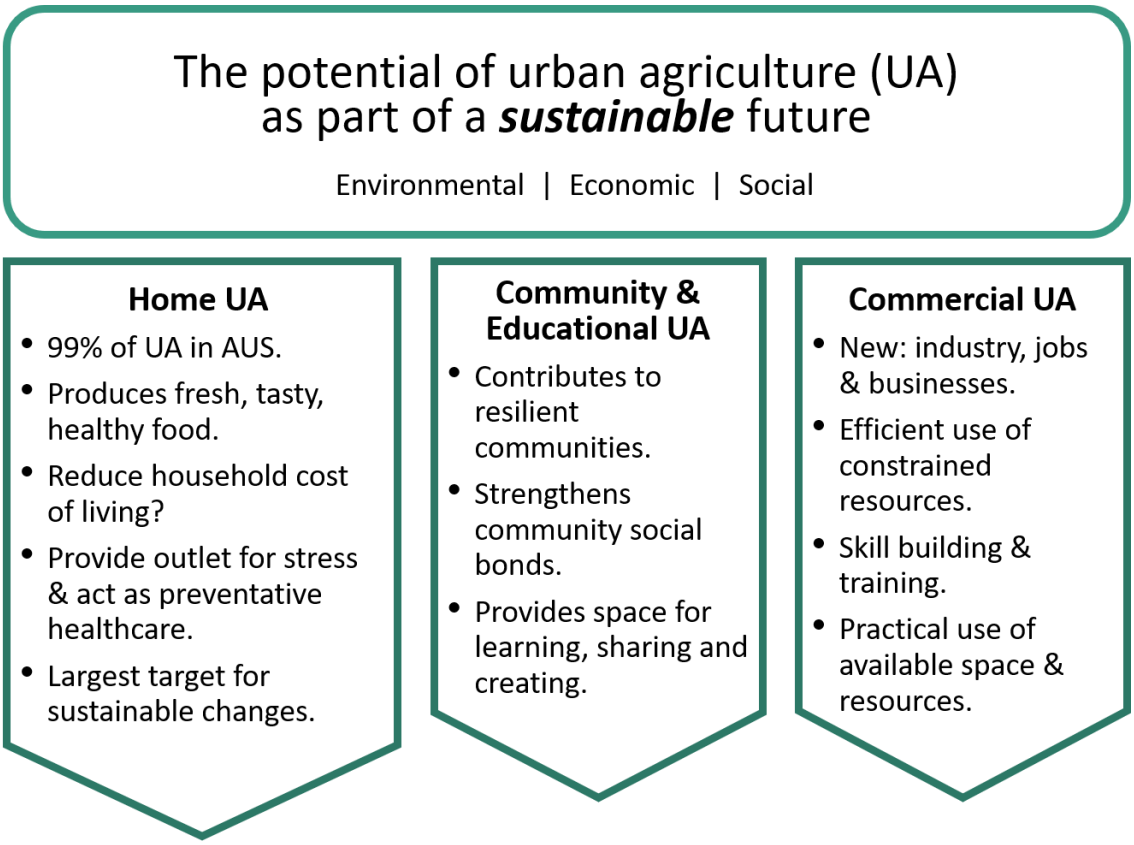

Figure 2: Identified components of the potential of UA to contribute to a sustainable future.

Home UA

At the household and local government level, there remains interest in whether producing food in urban spaces can help households save money and reduce their cost of living. Putting aside for a 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 (Barthel et al. 2013a; Barthel et al. 2013b; Kemp 1977; Kim 2014; Matos et al. 2013a)) is still accessible in modern urbanised areas. The implications are far-reaching: if home UA is purely a middle-class discretionary activity, then it will play a limited role in improving food security on a citywide scale.

Similarly to countries such as the United States, the United Kingdom, and Germany, Australia is a place of high food security and relatively low food prices. In overall food security, Australia is ranked fifth out of the 113 countries listed by the Global Food

Security Index (The Economist Intelligence Unit 2017). With regard to food affordability, food constitutes only 10% of total consumer expenditure in Australia—a percentage comparable to those in the US (6%), United Kingdom (8%), Germany (10%), and Japan (14%) (United States Department of Agriculture (USDA) 2017). Although a country of relatively high food-security, there are still many Australian households who would benefit if growing some of their own food could save them money on their food bills. A report by the Australian Bureau of Statistics (ABS) (2015c) 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, has also been found to be a serious fiscal challenge for welfare-dependant households (Kettings et al. 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 (Australian Bureau of Statistics (ABS) 2015b).

It remains unclear whether it is feasible for households to save money by growing some of their own food, if all the relevant inputs and their associated costs are taken into account (Ward, J et al. 2017). In addition to the need to consider labour, costs, and water as inputs in their own right, we must also consider the impact of these inputs on the economic sustainability of home food gardens. If the setup or maintenance costs of an urban food garden prove too great a barrier to households wanting to save money, then growing food should no longer be promoted in such a way. Moreover, if UA is intended to be an integral part of our vision for the sustainable city, then it is imperative to know whether the inclusion of UA in this vision adds a net savings or a net cost. Certain garden setups may lend themselves to higher productivity, higher water efficiency, lower labour input, and/or lower costs than others. But without further research into the variety and effectiveness of the myriad garden setups currently used in home food gardens, no recommendations can as yet be made.

Community and Educational UA

Community Gardens

Community gardens help provide typically positive public demonstrations of co-operative food and space-sharing production. UA is an increasingly popular mechanism for connection to smaller local landscapes and communities, and can help redefine individual and community-focussed values. Participants in the study by Pollard (2014) linked growing, harvesting, cooking, sharing and eating food, as ways to express values of care, support and knowledge sharing. People looking for meaningful social activities and who enjoy gardening are turning to community gardens (Lloyd, D 2015). This engagement can help to develop stronger social relationships (Thornton 2017), a sense of social cohesion (Bellows et al. 2003), and increase the social capital of those involved (Kingsley et al. 2006; Twiss et al. 2003). Participation in community gardens has also 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). Food grown in community gardens can be shared among a diverse range of people, including family, friends, community groups and strangers. Indeed, Vitiello et al. (2010) noted the surprising result that nearly all of their community garden participants reported sharing produce with those who are hungry.

Furthermore, engagement in community gardening can play a valuable role in promoting urban sustainability (Evers and Hodgson 2011, Lyons et al. 2013), and as advocated by Turner (2011) can even help encourage deeper, "long-term commitment to sustainable living practices" (pg. 520). Similarly to non-food gardens, well-designed UA areas (including community gardens) can help support local biodiversity and ecosystem services. This can be done by increasing plant-species richness (food plants, ornamentals and natives), encouraging varied vegetation structure and by reducing areas of impermeable surfaces (Clarke et al. 2015; Lin et al. 2015).

With regards to productivity, only a small number of studies have measured or estimated the yields of community gardens. The reported yields vary but are not insignificant, with averages ranging from 0.9 kg/m2 to 5.8 kg/m2 (Gittleman et al. 2012;

McGoodwin et al. 2016; Pourias et al. 2015; Rabin et al. 2012; Vitiello et al. 2010). The subsequent collection of data on the resource efficiency of community gardens, however, thus far remains relatively unstudied.

School Gardens

The relationship between children, nature and food is an important one. Engagement of primary school-age children in regular place-based outdoor learning was found to not only improve academic skills such as writing, vocabulary development and oral language ability, but also helped to promote social skills, leadership, resilience and independence (Lloyd, A et al. 2018). Nature based interactions can even have flow-on effects into adulthood. Remembered childhood participation in both "wild" and "domesticated" nature (including harvesting food) was found to be positively associated with pro-environmental attitudes in adults, and to some extent pro-environmental behaviours also (Nancy et al. 2006). Being part of the physical production of food is also recognised as a way to encourage increased fruit and vegetable intake in children (Somerset et al. 2005). There is some concern over children's lack of connection to nature and low understanding of where food comes from (Pollard 2014; White 2004). In interviews conducted by Pollard (2014), every discussion on what the interviewees valued about UA led inevitably back to the benefits and value of food experiences and education for children.

Like community gardens, school gardens constitute a small fraction of overall UA activity, but can still have a considerable positive impact on the children and people involved. While it is difficult to estimate the number of schools with non-formal food gardens, one formal Australian example is the Stephanie Alexander Kitchen Garden Program. This program has more than 800 registered schools across Australia, 92 of which are in South Australia (Stephanie Alexander Kitchen Garden Foundation 2014). The program aims to "see children form positive food habits for life" by offering pleasurable food education on how to grow, harvest, prepare and share, "fresh, seasonal, delicious food". Qualitative results from the study by Block et al. (2012) reported increased perceptions of student engagement and confidence, and that being involved in the Stephanie Alexander Kitchen Garden Program helped students learn

teamwork, build social skills and form connections with their communities. Improved social behaviours were also reported by both the teachers (86%) and parents (50%) involved in a national program assessment by Yeatman et al. (2013). There is also some potential for demonstration of garden measurement techniques to act as a useful mechanism for fun, hands-on and applied learning of Science, Technology, Environment and Mathematics (STEM) topics.

Both community and school gardens are examples of public demonstrations of co-operative food production, where people can come together to grow food, learn new skills, share knowledge, form positive social connections and reconnect with nature. Such spaces are valuable for sustainable cities of the future, particularly in support of social (and often environmental) sustainability. The economic sustainability is an aspect of community and school gardens which would benefit from further research. There is a need for a stronger focus on basic measurements, quantitative data collection and monitoring of the productivity and resource efficiency to fully understand the contribution of community and educational UA.

Commercial UA

There is some expectation that the increasing interest in UA will stimulate the emergence of a new industry of UA businesses. As a forerunner to this, UA is currently promoted by some, as a sort of new-age agrarian livelihood, complete with the development of practical growing guides to help support those wanting to get into commercial UA production. Examples of such guides include, SPIN Farming (small plot intensive) (Stone 2018), the deep-organic techniques of Eliot Coleman (Coleman 2009) and the low-tech, high yielding methods practised by Jean-Martin Fortier (Fortier 2014).

For areas experiencing a post-industrial slump as manufacturing and/or other industries shift or shut down, commercial UA is viewed as a potential replacement to provide work and to make the most of the vacant urban land. The city of Detroit is one example of a city interested in the post-industrial future of UA. Detroit has many organisations involved in variations of education, training, community engagement, not-for-profit and for-profit food production (Held 2015). Colasanti et al. (2010) used

GIS mapping to identify what they called a "conservative estimate" of 4,848 acres of vacant land across the city of Detroit which could be used for commercial UA. Here in South Australia, Adelaide has also recently experienced its own closure of the large Holden Car Factory, resulting in almost 1,000 employees out of work. Debate continues about what to do with the site and what other employment options are open to the newly unemployed. Nearby to the closed factory, the council area 'City of Salisbury', has also long been interested in making effective use of the land and collected stormwater water they have available, but thus far nothing has been established (Ward, P et al.).

The wide variety of existing UA organisations and businesses can make assessing the commercial potential of UA a complex process. Both Nugent (2000) and Petts (2005) list the main challenges of calculating the economic worth of UA, including: (1) the variation of production in different seasons, cities, and in different years; (2) how small profits made by informal urban farmers tend to go mostly unreported as many do not consider UA a 'real' job; and (3) how variations in food prices over time and between different sellers can make profit/viability difficult to compare.

Currently lacking from the environment surrounding emerging UA businesses is a trusted body of knowledge and data providing industry benchmarks for the process of UA commercialisation. Data collected from further research into all forms of UA, could be used to form a framework of sustainable UA business-cases. It is imperative that we critically evaluate the current state of UA; as without an understanding of the productivity, resource efficiency and social value of the myriad setups currently used to grow food in urban spaces, no recommendations can be made for the future.

The Challenges of Past UA Research

Urban agriculture is deeply rooted in multiple parts of the urban and fringe landscapes in which it exists, and thus it differs in each place accordingly. To properly consider the urban agriculture of a place – an individual food garden, or the gardens of a local area, town, city or state, one must consider all the elements of the climate and environment, available resources, available space, legislation and policy, cultural and social systems, and of course the motivations, experiences, challenges and expectations of the people

involved. 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 typically low physical accessibility and visibility (Conway et al. 2014; Kortright et al. 2011; Taylor et al. 2013).

Initial interest into 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 (Algert et al. 2016; Algert et al. 2014; Cleveland et al. 1985; Orsini et al. 2014; Pourias et al. 2015; Richards et al. 2015; Stall 1979; Stephens et al. 1980; Utzinger et al. 1978; Vitiello et al. 2010; Vitiello et al. 2009), short data collection periods (Algert et al. 2016; Algert et al. 2014; Conk 2015; Stephens et al. 1980; Vitiello et al. 2010; Vitiello et al. 2009; Zainuddin et al. 2014), and the difficulty of measuring critical inputs such as labour, costs and water use. In particular, measurement of the water used by UA has been habitually overlooked, even within research on UA yields (Ward, J et al. 2014). Water is a fundamentally limiting – and potentially costly – resource for UA, yet there is little scientifically-collected data on the water use efficiency of existing cultivation techniques used, nor a strong awareness of how much water people apply to their food gardens (Mok et al. 2014; Wortman et al. 2013). Research into productivity and efficiency aspects of UA faces many practical challenges, yet it is also a field with great potential.

This thesis contributes significantly to the field of UA by systematically identifying and addressing practical aspects of the productivity, resource efficiency and social value of UA, with a particular focus on home food gardens which constitute the overwhelming majority of urban food production activity, yet until now, have remained largely overlooked. The following sections in this chapter detail the overall aim and objectives of this research, provide a short summary on the main project involved (publicly titled "Edible Gardens"), and outline the structure of the thesis including the positioning and context of four peer-reviewed open-access published papers and one submitted paper under consideration pertaining to this research.

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Research aims, objectives and actions

As each of the following chapters describe separate parts of the design, methods, management and application of this research and the Edible Gardens project, presented below is a cohesive overview.

The key aim of this research was,

> ***"To investigate the productivity, resource efficiency and social value of urban food gardens in South Australia."***

This aim was divided into four objectives, with subsequent actions listed beneath each individual objective:

1. ***Assess the scope of previous urban agriculture measurement research in developed countries and identify gaps in data and measurement procedures.***

    a. Assessed and critically evaluated all past in-field urban agriculture measurement research in developed countries.

    b. Identified water use measurement as a severely overlooked issue.

    c. Identified the lack of detailed input data including: water use, time spent on different activities and full costs (set-up and maintenance costs).

    d. Investigated the inherent challenges of conducting research on urban agriculture and what research approaches had been used previously.

    e. Evaluated citizen science as a potential research approach capable of overcoming most of the identified challenges.

2. ***Develop and implement a novel approach to enable widespread measurement of urban agriculture input and yield data on existing urban food gardens.***

    a. Selected citizen science as an appropriate and effective approach for future urban agriculture research.

    b. Designed the Edible Gardens project – a citizen science project of the Discovery Circle and the University of South Australia. Launched the

Edible Gardens project in September 2016:

Phase 1: An online survey to collect data on gardener's motivations, any challenges, their years of experience and from where they learned to grow food. Respondents 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.

c. Planned Phase 2: In-field garden data collection by a selection of participants. Selected participants are to measure and record data on their food garden inputs (including time spent on different gardening activities, costs and water use), any yields they harvest and any part of their harvest they give away to others.

d. Designed additional project features including a data collection toolkit to assist selected participants collect data on their own food gardens, and customised online infrastructure. The online infrastructure includes a data base for data storage, and an interactive web interface.

e. Tested the tools planned for the data collection toolkits (different water meters and scales).

f. Used the information gathered by the online survey and tool testing to improve and adapt the second phase of the project before selecting chosen participants to collect data on their own gardens.

g. Launched Phase 2: Selected participants from the list of survey respondents to collect data on their own food gardens. Guided the participants through registration, customised data collection toolkits to suit each individual food garden and kept in regular contact with the participants via regular project updates.

3. ***Clean, manage and analyse collected data from both Phase 1 and 2 to gain an in-depth understanding of existing state urban food gardens in South Australia.***

a. Utilised a combination of quantitative and qualitative statistical analysis to investigate the social value of urban food gardens and the role this may play in supporting the mental wellbeing, social connection and happiness of urban food gardeners.

b. Calculated the overall productivity of the urban food gardens registered in Phase 2 and evaluated any variability between different gardens and the reasons behind this.

c. Evaluated and compared the overall resource efficiency of different garden setups, with particular attention to water, labour, costs and area under production.

4. ***Respect and acknowledge the reciprocal relationship with the 'citizen scientists' (survey respondents and selected phase 2 participants) who contribute data.***

a. Provided clear descriptions of what was expected of participants, what they would receive in return and how their contribution would support urban agriculture research.

b. The citizen scientists were always able to access their own data and download it for their own uses, in addition to having access and being able to interact with their own data online using the interactive chart visualisations where they could also compare their results with those of other participants.

c. All written articles based on the Edible Gardens projects were published 'open-access' to ensure that anyone can access, read and download them. Each acknowledgement section also contained a thank you to the participants.

d. All those citizen scientists who collected data on their own gardens received a customised final report detailing their results – what they harvested, how their different areas compared, and what the estimated retail value and nutritional value of all the food they produced was worth.

Summary of the Edible Gardens Project



Edible Gardens was a state-wide citizen science project created solely to investigate the productivity, resource efficiency and social value of urban food gardens. It was open to all forms of urban food production, including home, community and school gardens.



The project was part of the Discovery Circle – a citizen science initiative of the University of South Australia. Approval from the Human Research Ethics Committee was received on the 8th of January 2016 (Protocol number 0000034940). The project ran from September 2016 until June 2018.

Edible Gardens had two parts, the first an online survey and the second a period of garden data collection. During September 2016 to April 2018, 402 South Australians responded to the initial online survey. More than half (58%) of the survey respondents volunteered to collect data on their own food gardens. 105 gardeners were selected and of those, 71 home gardens and 2 school gardens proceeded to register their gardens via the Edible Gardens webpage. The gardeners who registered received customised data collection toolkits to support their collection of a variety of physical input and output data. Although 20 community gardeners completed the online survey, in the end none wished to collect garden data. Over the course of 17 months, 34 home gardeners and one school garden consistently collected and entered data into the project's online web interface. These participants were able to choose the length of time they wished to collect garden data for, from as short as 1 month to as long as the full 17 months.

Structure of the thesis

This thesis is divided into eight chapters consisting of four peer-reviewed, open-access journal papers and one journal paper intended to be submitted at the same time as this thesis. Each chapter is individually introduced before the major research findings are then brought together as a cohesive whole in chapter 7 (see Figure 3).

This work is submitted as a Thesis Containing Published Research in accordance with UniSA Academic Regulations for Higher Degrees: Research Clause 16.1.1.b (http://www.unisa.edu.au/policies/policies/research/res10-regs.asp)

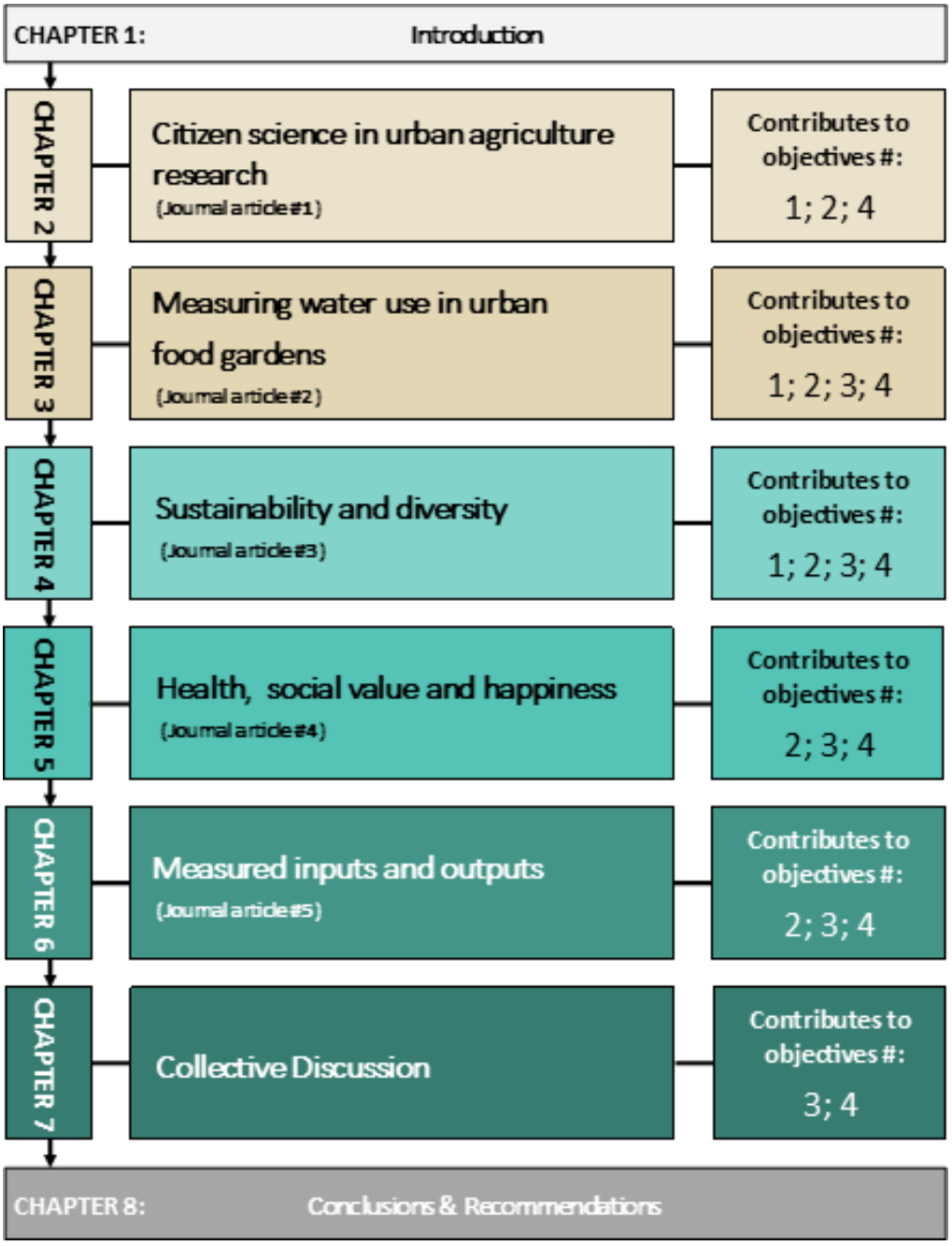

Figure 3. Overall thesis structure and the contribution of each chapter to the four research objectives.

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The University of South Australia

The Discovery Circle

The Adelaide and Mount Lofty Ranges Natural Resources Management Board

The Government of South Australia: Department of Environment Water and Natural Resources

The City of Salisbury

The City of Marion

List of Publications

From this research four peer-reviewed, open-access journal articles were produced, with one final paper intended for submission at the same time as this thesis.

Journal papers

1. **Pollard G**, Roetman P and Ward J, The case for citizen science in urban agriculture research, *Journal of Agriculture, Food & Society, 5 (3) (2017), 9-20.*

2. **Pollard G**, Ward J and Roetman P, Water use efficiency in urban food gardens: Insights from a systematic review and case study, *Horticulturae, 4 (3) (2018) 27.*

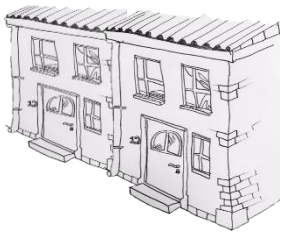
3. **Pollard G**, Roetman P and Ward J, Typically diverse: The nature of urban agriculture in South Australia, *Journal of Sustainability*, 10 (4) (2018) 945.

4. **Pollard G**, Roetman P, Ward J, Mantzioris E and Chiera B, Beyond Productivity: The Mental health, Social Wealth and Happiness of Urban Food Gardeners, *Urban Science*, 2 (4) (2018) 97.

   Intended for Submission

5. **Pollard G**, Ward J and Roetman P, Productivity, Resource Efficiency & Financial Savings: An Investigation of the Current Capabilities and Potential of South Australian Home Food Gardens.

2 Citizen Science in Urban Agriculture Research



Overview

While considering the place of urban agriculture in modern developed countries today, the question is posed, "Is urban food production still capable of its original purpose (i.e. to help supplement the fresh food supplies and reduced incomes of the urban poor), or has it become for the most part a purely middle-class discretionary activity?" Answering this question requires a better understanding of urban food gardens as they currently exist. And as the demand for research into urban agriculture increases, so too does the need for larger-scale data collection. Data from the individual household level is required and yet collecting these data remains logistically challenging.

Early research involved small-scale studies with scientists collecting data on a few purpose-built experimental gardens. Existing urban food gardens are difficult to research for several reasons. They are typically placed on private property, therefore requiring permission to access, and are widely spread across towns, suburbs and cities. They are also often visibly hidden in people's backyards making their presence hard to notice from the street. Additionally, there is the substantial diversity of garden setups, growing techniques, water sources and irrigation methods. This diversity can be challenging to account for when designing a data collection method. For one scientist, or even a team of scientists, gaining access to multiple gardens for daily, weekly or monthly data collection can quickly become logistically impossible. However, a citizen science approach, where members of the public are engaged and trained to collect data on their own urban food gardens, makes data collection possible. In this chapter, citizen science is defined by Louv et al. (2012) as, "public participation in organised research efforts". When applied to urban agriculture, citizen science can work to bypass or mitigate many of the inherent challenges of research into food gardens.

This chapter begins by describing different forms of urban agriculture, with some reference to historical examples and applications. The paper goes on to critically

review early urban agriculture yield and productivity studies from the 1970s and 1980s and then the more current research published from 2009 onwards. The main challenges of researching urban agriculture are reviewed, with particular emphasis on how these challenges have inhibited advances in urban agriculture research. The concept of 'citizen science' and its overall philosophy are introduced. Examples of the use of citizen science in previous urban agriculture research are provided. Finally, the Edible Gardens project and its research design are presented. This project provides a South Australian example of how a citizen science approach can overcome or mitigate the majority of research challenges when studying in-field urban food gardens.

This chapter contributes to research objectives:

1. *Assess the scope of previous urban agriculture measurement research in developed countries and identify gaps in data and measurement procedures.*

2. *Develop and implement a novel approach to enable widespread measurement of urban agriculture input and yield data on existing urban food gardens.*

4. *Respect and acknowledge the reciprocal relationship with the 'citizen scientists' (survey respondents and selected phase 2 participants) who contributed data to the Edible Gardens project.*

The related appendix of this chapter (Appendix A) provides information on the different tailored strategies used by the Edible Gardens project to engage home, community and school gardens. The challenges of trying to incorporate this mixture of food gardens are also documented and discussed.

This paper was published in the Future of Food: Journal on Food, Agriculture and Society in 2017 (Paper #2). The manuscript was co-authored by my supervisors, Dr James Ward and Dr Philip Roetman from the University of South Australia.

Author Contributions: G.P., J.W., and P.R. conceived of and designed the EG project and survey; G.P. conducted the literature review and designed and tested the data collection toolkits; and G.P., J.W., and P.R. wrote the paper.

The format of this paper has been altered for consistency with the rest of the thesis.

Paper 1: The case for citizen science in urban agriculture research

Published as: Pollard, G., Roetman, P., & Ward, J. (2017). The case for citizen science in urban agriculture research. *Future of Food: Journal on Food, Agriculture and Society, 5*(3), 9-20.

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.

Keywords: Citizen science, public participation, urban agriculture, quantitative measurement, economics, food production.

1. Introduction

Although there has been a recent revival of interest and engagement in urban agriculture in the developed world (Matos et al. 2013; Schupp et al. 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 et al. 2015; Taylor et al. 2013; Ward et al. 2014b; 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 et al. 2008; Balmer et al. 2005; Galhena et al. 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 et al. 2014; Gerster-Bentaya 2013; Ward et al. 2017; Ward et al. 2014a). 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 et al. 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.

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 et al. 2014; Kortright et al. 2011; Taylor et al. 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 et al. 1985; Pourias et al. 2015; Stall 1979; Stephens et al. 1980; Utzinger et al. 1978; Vitiello et al. 2010; Vitiello et al. 2009), short data collection periods (Conk 2015; Gittleman et al. 2012; Stephens et al. 1980; Vitiello et al. 2010; Vitiello et al. 2009; Zainuddin et al. 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 et al. 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 et al. 2013a; Barthel et al. 2013b; Kemp 1977; Kim 2014; Matos et al. 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 et al. 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 et al. 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 (Australian Bureau of Statistics (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 et al. 2006) and increase access to fruit and vegetables, especially in low-income areas (Armstrong 2000; McCormack et al. 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 et al. 2017).

Citizen science is defined as "public participation in organised research efforts" (Louv et al. 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 et al. 2007; Williams et al. 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 et al. 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 et al. 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 demonstrates 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.

2. 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 et al. 1978), while the fifth collected estimated survey data from pre-existing home vegetable patches of small farms (Gladwin et al. 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/m2 (Stall 1979; Utzinger et al. 1978), while another two reported lower yields of between 1.2-2.7 kg/m2 (Cleveland et al. 1985; Stephens et al. 1980). Gladwin et al. (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 et al. (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 et al. 1998; Lawson 2004; Schmelzkopf 1995), related health benefits (Brown et al. 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 et al. 2014b). 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 et al. 2014; Conk 2015; Zainuddin et al. 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 et al. 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/m2 (Gittleman et al. 2012; Vitiello et al. 2009), three studies reported intermediate yields of between 2-4 kg/m2 (Algert et al. 2014; Conk 2015; Vitiello et al. 2010), and three studies reported lower yields of between 0.35-1.7kg/m2 (Codyre et al. 2014; Pourias et al. 2015; Zainuddin et al. 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 et al. 2014). All but one study (Zainuddin et al. 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.

3. Issues with past research into urban agriculture productivity

Home food gardens have been considerably overlooked with regard to research, interest and support (Conway et al. 2014; Taylor et al. 2013; Zainuddin et al. 2014). This is particularly true in comparison to community gardens (Golden 2013; Gray et al. 2014; Kortright et al. 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 et al. 2014; Kortright et al. 2011; Taylor et al. 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.

3.1. 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 et al. (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.

3.2. 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 (Hawkins 2014; Vitiello et al. 2010; Vitiello et al. 2009) or commercial yield rates and input requirements (Garnett 2000; Ward et al. 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 et al. (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.

3.3. Water as an input

Very little is known about the current water consumption of UA (Ward et al. 2017; Ward et al. 2014b). 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.

3.4. 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 et al. 1982; Stall 1979; Utzinger et al. 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 measurable 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.

3.5. 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 et al. 2014; Ward et al. 2014a). Recorded yields from past UA research ranged from as low as 0.35 kg/m2 (Zainuddin et al. 2014) to as high as 6.85 kg/m2 (Utzinger et al. 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 et al. 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. 2013b). By comparison, there is currently concern over the disparity in food growing knowledge and skills between single generations (Barthel et al. 2013a), in

addition to discussions about the loss of skilled labour in traditional farming (Millar et al. 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 et al. 2014a). 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.

4. Citizen science

Home food gardens remain challenging to study due to their sheer diversity, geographic spread, low visibility and physical accessibility (Conway et al. 2014; Kortright et al. 2011; Taylor et al. 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 et al. 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.

4.1 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.

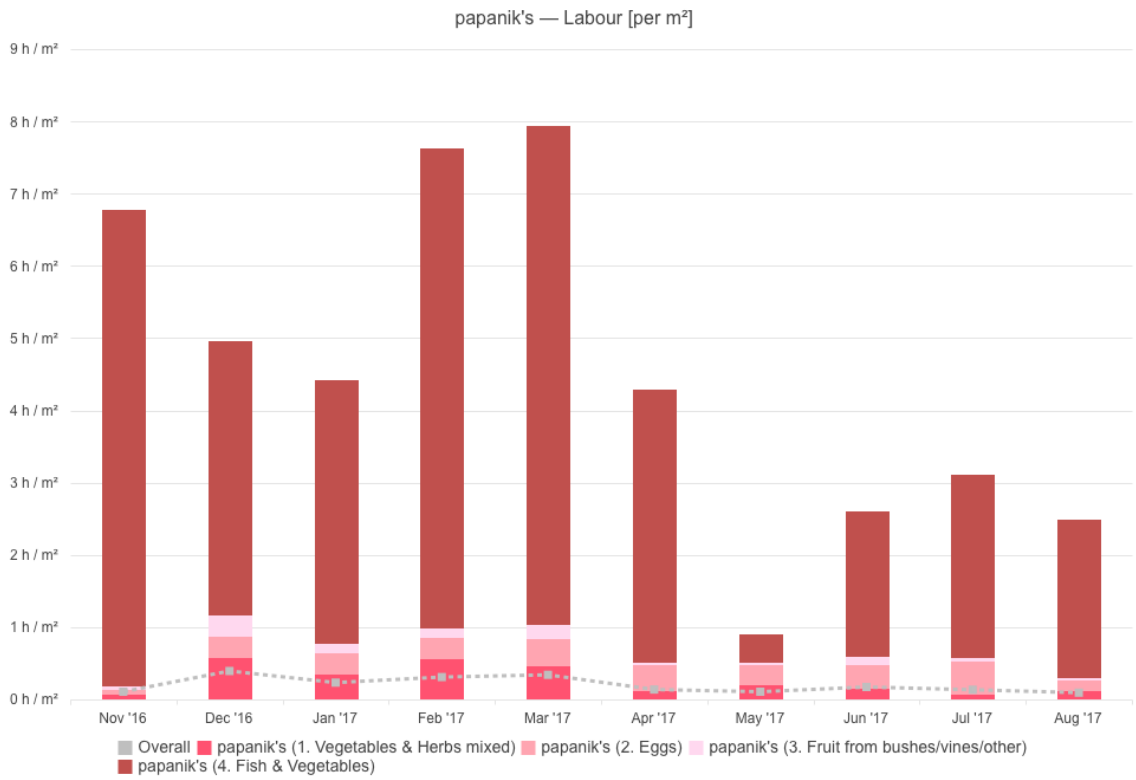


Figure 1. Labour invested per square metre for four growing areas in one garden

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 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 (Figure 2). 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 of 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.



Figure 2. Measuring three different gardens

Regarding 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. 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 publicly 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 et al. 2011).

5. 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 research (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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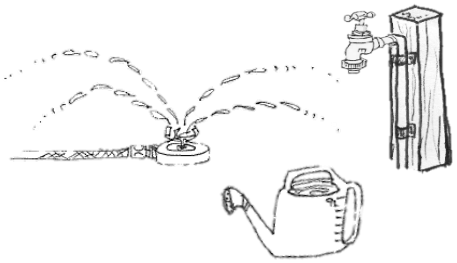
3 Measuring Water Use in Urban Food Gardens



Overview

Water use in urban agriculture (UA) can be enigmatic; it is rarely quantified and is frequently overlooked in research. Gardeners typically apply water to their gardens with greater awareness of the time spent watering than the volume of water being applied. This chapter was born of a desire to strip back some of the mystery, and to help improve the collective understanding of water use in UA in general, and water use efficiency in UA in particular. This paper first describes water use efficiency (WUE) as, "a measure of how efficiently production systems convert water (rainfall and/or irrigation) into a harvestable yield or into money", before exploring ways to apply such measures in urban agriculture.

When considering sustainable cities of the future, UA has several conceivable applications, whether as a small-scale commercial industry of fresh urban food supplies, acting as a dependable food source, or simply as a way for households to grow some of their own healthy food and to help reduce their cost of living. Each of these applications requires careful consideration of the productivity, resource efficiency and economic feasibility of the different forms of UA. Water is a key element of each of those considerations, yet has remained consistently overlooked in the majority of previous UA research. The lack of knowledge on water use in UA warrants concern as issues of water supply, access and cost increase globally.

This paper aims to critically evaluate the current state of UA research and its consideration of the water use and WUE of UA, using the PRISMA systematic review process. Of the 4,329 records identified from 1975 to 2018, 30 articles met the criteria for

inclusion in this review and of those, only five articles reported collecting UA water use data. Due to such a small number of eligible articles containing water use data, the second half of the paper proceeds to introduce South Australia as a demonstration of the practical difficulty of measure UA water use. This includes a discussion of the variety of urban water sources, water prices and irrigation methods available to South Australian urban food growers. In an effort to offer some tools to help assess the potential contribution and effectiveness of UA, four new equations to calculate the WUE of UA are proposed and demonstrated. The paper offers advice for future UA research to include two key measurements: 1) Overall water use, including the relative contributions by rainfall and irrigation, and – if possible – an estimate of change in soil moisture conditions; and 2) Yield per crop category. These two measurements would allow the basic WUE equation to be reported, which would represent a major improvement in UA research. However, it would also allow more detailed WUE equations to be reported (or post-processed by other researchers) in order to compare studies more meaningfully. Also provided is a table of recommended key food garden details which should be consistently reported, along with practical measurement suggestions for both yield and applied water use.

Improved collection of UA water use and yield data will provide a firm basis for further evaluation of how much water is being applied to UA gardens, their WUE and the comparison of different irrigation and cultivation techniques. It will also assist with calculation of the cost of water applied – thereby allowing more comprehensive economic evaluations of UA and assisting in its further optimisation. This paper provides a platform for future research into the WUE of UA to build upon. Only once these practical evaluations of existing UA production have been completed, will we have a clearer understanding of what UA currently contributes to our society and what future prospects may be possible within the constraints of urban water supplies.

This chapter contributes to research objectives:

1. *Assess the scope of previous urban agriculture measurement research in developed countries and identify gaps in data and measurement procedures.*

2. *Develop and implement a novel approach to enable widespread measurement of urban agriculture input and yield data on existing urban food gardens.*

3. *Clean, manage and analyse collected data from both Phase 1 and 2 to gain an in-depth understanding of current urban food gardens in South Australia.*

4. *Respect and acknowledge the reciprocal relationship with the 'citizen scientists' (survey respondents and selected phase 2 participants) who contributed data to the Edible Gardens project.*

This paper was published as a paper in the journal Horiculturae in 2018 (Paper 2). The manuscript was co-authored by my Principal Supervisors, Dr. James Ward and Dr. Philip Roetman from the University of South Australia.

Author Contributions: Conceptualisation, Methodology & Investigation by G.P., J.W. and P.R.; Writing-Original Draft Preparation by G.P.; Writing-Review & Editing by G.P., J.W. and P.R.; Supervision by J.W. and P.R.

The format of this paper has been altered for consistency with the rest of the thesis.

Paper 2: Water use efficiency in urban food gardens: Insights from a systematic review and case study

Published as: Pollard, G.; Ward, J. and Roetman, P. Typically diverse: The nature of urban agriculture in South Australia. *Horticulturae* 4 (3) 2018, 27.

Abstract

Water use and the cost of water are key factors when considering the net value of urban agriculture (UA). This systematic review critically evaluates past and recent UA yield research from the perspective of water use efficiency. A systematic literature search was conducted using the databases Scopus, ProQuest Agriculture and Environment, and Web of Science for references from 1975 to 2018, with 25 articles meeting the inclusion criteria. Of these, only five articles had actively collected UA water use data, all on purpose-built experimental gardens. Considering the scarcity of UA water use efficiency and water measurement literature, South Australia is presented as a case study to demonstrate the considerable diversity of water pricing,

water sources and irrigation methods available to urban food growers. The practical challenges of garden placement and the wide variety of cultivation techniques, water sources and irrigation methods are reviewed. Four equations to calculate the water use efficiency (WUE) of UA are proposed and demonstrated. Collection of additional UA water use data would support more robust evaluations of the water use efficiency and economic implications of different cultivation techniques. Further work in this field will enable a realistic understanding of the current and future contribution of UA to our society.

Keywords: urban water management, urban agriculture, food production, water efficiency, measurements, crop irrigation

1. Introduction

The production of food in urban environments, also known as urban agriculture (UA), has a number of positive benefits for those who grow some of their own food, including: supporting urban food security and re-connecting people with their food systems (Bastian et al. 2012; Hinrichs 2000), encouraging positive dietary changes leading to better health (Alaimo et al. 2008; Bazzano et al. 2002), and supporting mental wellbeing through connection to nature (Freeman et al. 2012; Lloyd 2015). Some UA produce has also been found to be fresher and more nutritious than produce trucked in from interstate or flown in from overseas (Altieri 2008; Pénicaud et al. 2011). While the research on UA has been diverse and informative, researchers have rarely taken into consideration some of the more practical and applied questions which underpin the viability of UA, namely:

- How efficiently does existing UA use the resources it requires?
- What is the productivity of existing urban food gardens?
- Does growing food in urban areas save people money?

This lack of research is concerning. As the world population continues to grow, so too does the demand for research into more efficient use of resources (Ghosh 2014). Scarcities of fresh water, fertile topsoil and fertiliser reserves are already serious issues

for many parts of the world (Eigenbrod et al. 2015). These issues are likely to become exacerbated in some regions by the impacts of climate change (Hennessy et al. 2007). The combination of limited resources, a growing population and climate change has the potential to contribute to an increase in food prices (Auricht 2010; Hennessy et al. 2007). In an attempt to mitigate such impacts, some consideration has been given as to whether technological advances can increase the productivity of UA to sufficiently supplement produce requirements of cities and other urban centres (Mok et al. 2014; Wortman et al. 2013). However, with no data on the input requirements, resource efficiency or productivity of existing UA, there is currently no baseline to improve upon. In particular, measurement of the water used by UA has been habitually overlooked, even within research on UA yields (Ward et al. 2014b).

The water use of UA plays a vital part in answering all three of the practical questions listed above. Water is a fundamental and limiting resource in UA, yet there is little scientifically-collected data on the water use efficiency (WUE) of existing cultivation techniques used, nor a strong awareness of how much water people apply to their food gardens (Mok et al. 2014; Wortman et al. 2013). WUE is a measure of how efficiently production systems convert water (rainfall and/or irrigation) into a harvestable yield or into money. More efficient production systems work to lower the volume of water inputted while ensuring or improving the harvestable quantities. Calculations of the productivity of UA must account for the volume of water required to grow that produce, in addition to its cost. Rising water costs (of water suitable and available for food production) could limit future uptake of UA. Indeed, for many people the cost of water may already be a limiting factor, albeit a hidden one. In South Australia, for example, land blocks typically possess a single residential water meter to record combined indoor and outdoor water use (Ward et al. 2014b). By combining the indoor and outdoor water use into one metered bill, residents are unlikely to be aware of the volume or cost of water being applied to their food gardens.

This paper has two parts. We first present a systematic review of past UA WUE research with a focus on water use measurement. Such a review is necessary as only a limited number of past reviews have discussed the importance of considering UA

water use and to some extent, available water sources (Brown 2016; Mok et al. 2014; Specht et al. 2014; Wortman et al. 2013). No existing review has focussed on the challenge of measuring UA water use. How can the WUE of different UA cultivation techniques be compared (or indeed UA WUE compared with commercial horticulture) if there is little empirically collected data to base it upon? This systematic review aims to clearly highlight the lack of empirical UA WUE and water use measurement research.

Due to the small number of eligible articles identified which reported physically measuring UA water use, the second part of this paper introduces South Australia as a demonstration of the practical difficulty of measuring UA water use. Adelaide, the capital of South Australia, is known for its mostly arid and semi-arid climates climate, dependency on multiple water supplies and history of recycled water schemes (Marks 2010). A comparison of South Australia's agricultural and urban water sources is provided, in addition to an overview of the range of household urban irrigation methods. Each of the main urban water sources for gardening are covered in detail, then the difficulty of measuring UA water use is assessed. The complementary approaches of the review and case study demonstrate that there is a crucial need for the collection of baseline data on the input requirements, resource efficiency and productivity of urban food gardens as they currently exist. The absence of UA water data necessitates the development of practical methods of measuring the water use of existing UA. A South Australian project is presented as one example of current research into UA water use measurement. Once enough baseline data has been collected and analysed, research can then begin into how to improve the WUE of various UA cultivation techniques.

2. Materials and Methods

The systematic review was conducted following the PRISMA Statement (Moher et al. 2009). The literature search was finalised in June 2018. It focused on any studies conducted from 1975 to April 2018. This extended timeframe was applied due to the limited number of eligible papers expected, in addition to the authors' prior knowledge of seminal research from the late 1970s onwards. The search was restricted

to studies conducted within the 51 countries categorised as having "Very High Human Development" by the United Nations Development Programme in their 2016 report (United Nations Development Programme 2016). For the systematic literature search, three databases, Scopus, ProQuest Agriculture and Environment, and Web of Science were selected. Both Scopus and Web of Science are large collections of mainstream, indexed research, widely used in PRISMA systematic reviews. The ProQuest Agriculture and Environment Database was also included due to its particular focus on agricultural and environmental research. As a review of the WUE of UA which requires both harvested yield and water use figures, the search for articles required two related but separate searches. The first search focussed on identifying any urban agriculture-type studies which specifically investigated or measured water-related inputs. We searched for articles published in English since 1975 which included the following keywords in their title or abstract: ("urban agriculture" OR "urban food production" OR "home food garden" OR "community garden" AND water AND (measurement OR efficiency OR consumption OR supply OR management OR source).

The second search focussed on identifying any urban agriculture-type studies focussed on yields, harvests and/or the economic value of the crops produced. We searched the same three databases for articles published in English since 1975 which included the following combination of keywords in their title or abstract: ("urban agriculture" OR "home food garden" OR "community garden" OR "urban food production" OR "home vegetable garden*" OR "home garden" OR "urban garden" OR "urban collective garden") AND ("economic value" OR empirical OR cost* OR saving* OR quantify* OR yield* OR harvest* OR product*).

From the three databases, only articles that were available to the authors in full text were considered. As part of the selection process we first reviewed each study's title and abstract. The articles themselves were then screened according to their full texts and searched for descriptions, references or methods of empirical UA measurements of water, yield or economic value.

3. Results

3.1 Study Selection

The electronic database search resulted in n = 1665, 2189 and 475 hits from Scopus, ProQuest Agriculture and Environment, and Web of Science, respectively (Figure 1). From these, 134 duplicates were removed. A total of 3987 articles were excluded based on their title and abstract. As a result, 210 full texts were reviewed in detail and assessed for eligibility with 25 articles finally selected for inclusion in this systematic review.

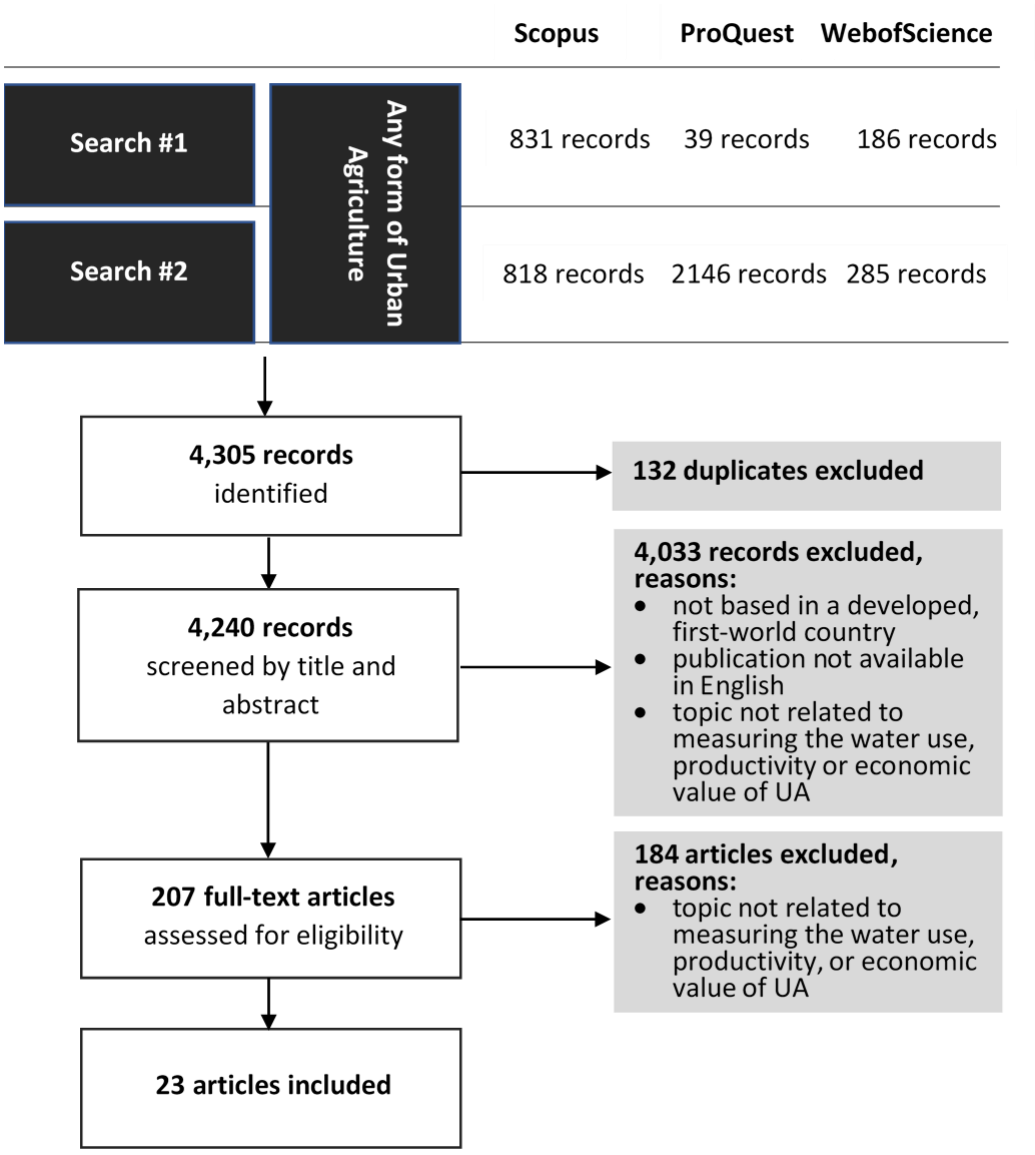


Figure 1. PRISMA flowchart outlining the systematic literature review selection process of articles published between 1975 to April 2018, sourced from three databases: Scopus, ProQuest Environment & Agriculture and Web of Science.

The lack of consistent keywords used in research related to UA necessitated the broad selection of keywords used. Naturally, such a broad search resulted in a large list of hits, many of which were irrelevant, hence the large number of articles excluded. Examples of some of the article topics considered irrelevant for this systematic review included mentions of UA related ecosystem services, soil chemistry or contamination, GIS spatial assessments of land available for UA in cities and any discussion of biofuel production from food or food-waste products.

An interesting exception to the articles found by the systematic review process are three quite relevant articles published in non-indexed journals, or as "grey-literature" reports. These articles include: Gittleman et al. (2012) and Vitiello et al. (Vitiello et al. 2010; Vitiello et al. 2009). Another two articles not found by the systematic review but nevertheless included by the authors, are the work by Stall (1979) titled, "Economic value of a home vegetable garden in South Florida" and Stephens et al. (1980) titled, "Economic value of vegetables grown in North Florida Gardens". Both are papers published in 'Proceedings of the Florida State Horticultural Society' and both are heavily referenced by the other early UA research from the 1970s and 80s. These five additional articles were included in this review due to their high relevance and common citation by other included articles, thus bringing the number of selected articles up to 30.

Of the 30 articles selected for this review, only five collected UA water use data (Table 1). Table 1 categorises all the articles by UA type, publication type and by their level of water data consideration.

Table 1. Categorisation of all studies to respective types and level of water data consideration

UA Type			
Home garden		Algert et al. 2016; Cleveland et al. 1985; Codyre et al. 2014; Conk 2015; Lupia et al. 2015; Pollard et al. 2018; Stall 1979; Stephens et al. 1980; Sullivan et al. 2015; Utzinger et al. 1978; Zainuddin et al. 2014	(10)
Community-style garden		Algert et al. 2014; Drake et al. 2015; Gittleman et al. 2012; McGoodwin et al. 2016; Pourias et al. 2015; Vitiello et al. 2010; Vitiello et al. 2009; Vogl et al. 2004	(8)
Technical assessment		Orsini et al. 2014; Richards et al. 2015; Sanjuan-Delmás et al. 2017; Sanyé-Mengual et al. 2015	(4)
Review, discussion or survey paper		Brown 2016; Langellotto 2014; Mok et al. 2014; Pollard et al. 2017; Pollard et al. 2018; Specht et al. 2014; Taylor et al. 2013; Wortman et al. 2013	(8)
Type of Publication			
Peer viewed, scientific publication		Algert et al. 2016; Algert et al. 2014; Cleveland et al. 1985; Codyre et al. 2014; Conk 2015; Drake et al. 2015; Gittleman et al. 2012; Langellotto 2014; Lupia et al. 2015; Mok et al. 2014; Orsini et al. 2014; Pollard et al. 2017; Pollard et al. 2018; Pourias et al. 2015; Richards et al. 2015; Sanyé-Mengual et al. 2015; Specht et al. 2014; Stall 1979; Stephens et al. 1980; Sullivan et al. 2015; Taylor et al. 2013; Utzinger et al. 1978; Vogl et al. 2004; Wise 2014; Wortman et al. 2013; Zainuddin et al. 2014	(26)
Book chapter		Brown 2016; McGoodwin et al. 2016	(2)
Grey literature		Vitiello et al. 2010; Vitiello et al. 2009	(2)
Level of Water Data Consideration			
HIGH	Collected empirical water data/ WUE data	Algert et al. 2016; Cleveland et al. 1985; Richards et al. 2015; Sanjuan-Delmás et al. 2017; Sanyé-Mengual et al. 2015	(5)
MED	Used existing water use data	Lupia et al. 2015	(1)
MED	Measured cost of water only	McGoodwin et al. 2016; Stephens et al. 1980; Utzinger et al. 1978	(3)
LOW	Measured other costs and/or inputs but no water data collected	Algert et al. 2014; Codyre et al. 2014; Gittleman et al. 2012; Stall 1979; Sullivan et al. 2015; Vogl et al. 2004	(6)
LOW	Did not consider costs or inputs and no water data collected	Conk 2015; Orsini et al. 2014; Pourias et al. 2015; Vitiello et al. 2010; Vitiello et al. 2009; Zainuddin et al. 2014	(6)
N/A	Review, discussion or survey paper	Drake et al. 2015; Langellotto 2014; Mok et al. 2014; Pollard et al. 2017; Pollard et al. 2018; Specht et al. 2014; Taylor et al. 2013; Wortman et al. 2013	(8)

4. Discussion of the Systematic Review

4.1 Existing WUE in UA research

Little is known about WUE in UA (Ward et al. 2014b). There has been a paucity of research in this area, despite the prevalence and increasing popularity of UA (Wise 2014). When compared with commercial horticulture, the irrigation applications and water consumption of UA production differ in several ways, including the size of land under production, the growing methods used, crop choices and planting arrangements. The majority of UA gardens support diverse polycultures instead of the more traditional monoculture crops of commercial horticulture and farming (Ward et al. 2014b). Different crops have different water requirements, so overwatering is common in polyculture situations (Ward et al. 2014b). Considering that both over and under watering can impact plant growth and therefore yield (Stirzaker, RJ 1999), there is limited utility in applying average commercial yield rates to UA gardens.

Studies investigating the economic costs and benefits of urban food gardens began appearing from the U.S.A. in the late 1970s (Cleveland et al. 1985; Stall 1979; Stephens et al. 1980; Utzinger et al. 1978). In these studies, experimental gardens were constructed to measure the input costs and calculate the retail value (and other values) of the produce harvested. Stall (1979) did not attempt to measure water use or the cost of the water applied to their study garden. Utzinger et al. (1978) and Stephens et al. (1980) recorded their water costs but did not record the volume of water used as an input.

Although water is one of the primary constraints of all plant growth (Postel 1998; Stirzaker, RJ 1999), historically it has not been considered an expensive input (Stirzaker, RJ 1999), and so potentially not an input worth measuring. Cleveland et al. (1985) were the first researchers to purposely measure and consider the volume of water applied as an input separate to cost. Being based in the urban desert environment of Arizona, they were interested in whether it was economically feasible for home gardeners to grow fresh, cheap produce in their area. Two gardens were built and, over periods of 2.5 and 3 years, all garden-related costs were recorded, including

straw mulch, manure, tools, water and labour. Every water application was measured (to nearest 0.1 cubic feet) using a standard water meter provided by the utility, with calibrated buckets used for small volumes. Rainfall and evapotranspiration rates were also recorded. Water was found to be the single largest expense, contributing almost 30% of the total cost of each garden. The act of watering by hand took approximately 50% of the total hours spent. Cleveland et al. (1985) found that small financial savings could be made by producing food using their methods, albeit at a lower returns per hour of labour than the minimum wage of the time.

These initial studies looked at the economic feasibility of urban food gardens for various USA States, and all collected data from purpose-built experimental gardens. Such experimental gardens may mimic a typical home food garden, but they differ in that they were designed, built and tended by scientists and not by everyday gardeners. Records from existing home food gardens would provide more realistic results and a greater understanding of the variability among gardens. Some urban food gardeners do keep yield records; however, such records are private and not often made public (Ward et al. 2014b).

More recent studies interested in quantifying urban food gardens have tended to collect data from existing home and community gardens, rather than building experimental gardens (Algert et al. 2016; Algert et al. 2014; Codyre et al. 2014; Conk 2015; Gittleman et al. 2012; Pourias et al. 2015; Vitiello et al. 2010; Vitiello et al. 2009; Vogl et al. 2004; Zainuddin et al. 2014). There are exceptions to this shift, with studies identified in the systematic review that instead focus on technical assessments of particular cultivation techniques, including investigations into the yields (among other factors) of raingardens (Richards et al. 2015), integrated rooftop greenhouses (Orsini et al. 2014; Sanjuan-Delmás et al. 2017), sub-irrigated planters (Sullivan et al. 2015) and other high-tech cultivation techniques (Sanyé-Mengual et al. 2015). Each of these studies designed, built, managed and collected data from their own experimental urban food gardens. The foci of these more recent studies were the measurement of yields, retail value calculations, and some full life-cycle or environmental assessments. However, similarly to the earlier studies, only four of the sixteen more recent studies

measured or reported water use as an input: Sanyé-Mengual et al. (2015), Richards et al. (2015), Algert et al. (2016) and Sanjuan-Delmás et al. (2017).

Sanyé-Mengual et al. (2015) conducted a life-cycle assessment of purpose-built experimental rooftop gardens from an environmental and economic perspective in Bologna, Italy. Using only mains water, they compared the water depletion as part of experimental trials of three cultivation techniques: nutrient film, floating hydroponic and raised soil garden bed. There was no mention of how the water applied was measured, although there was a description of using timers to control the application of set volumes of water. Sanyé-Mengual et al. (2015) found the floating hydroponic system to be the most water efficient of their three cultivation techniques.

Around the same time (2015), Richards et al. (2015) ran an 18-month field trial in Melbourne, Australia to test the yield productivity, irrigation requirements and runoff capture of experimental vegetable raingardens (these are garden areas designed to slow down and absorb excess rain and stormwater). Such gardens are typically planted with tough plants able to withstand both flood and drought conditions—this makes attempting to grow vegetables in a raingarden an interesting choice. Four raised vegetable beds were built. Two of the beds were irrigated only via surface micro-spray irrigation (one with mains water and one with collected rainwater). The other two beds (one lined and one not) were sub-irrigated by rainwater via connected downpipes. The water sources, irrigation methods, volume of water applied and irrigation requirements of all four beds were measured, yet the measurement method was not described. Although the lined raingarden bed was found to be the least productive yield-wise, it was still found to reduce the volume and frequency of runoff and did not require supplementary watering during summer.

The study by Algert et al. (2016) investigated the contribution of home gardens to cost savings and improved nutrition for low-income households in San Jose, California USA. Participants of the La Mesa Verde Project were provided with two raised garden beds to take home and set up; each bed was 3 m2 and included soil, seedlings and seeds. Eight gardeners agreed to weigh their harvested produce for the 17-week study period and four of those gardeners also agreed to measure and record their water use.

Water meters were attached to dedicated backyard hoses (it was not noted whether those taps were mains water or not). The gardeners recorded the volume of water used (in gallons) in an irrigation log each time they watered their garden. The cost of the water was calculated according to local water company prices and was found to have an estimated cost of US$2.96 per month, per garden. No WUE calculations or comparative analyses with the productivity of the gardens were made.

More recently, Sanjuan-Delmás et al. (2017) conducted an assessment of experimental integrated rooftop greenhouses, also known as i-RTGs, in Barcelona, Spain. The enclosed rooftop of a research centre was retrofitted to incorporate four greenhouses. This integrated arrangement was thought to provide benefits to both the productive plants and the building itself, such as improved temperatures in both summer and winter. The building had an existing rainwater harvesting system, utilised to provide the majority of the water for the greenhouses (80–90%), supplemented by mains water (10–20%). Tomato plants were grown hydroponically over 15 months, and spring and winter tomato crops were compared. Sanjuan-Delmás et al. (2017) also compared the WUE of their i-RTG tomato crops with those of standard greenhouses and found that the standard greenhouses performed better in both summer and winter.

Although there has been a variety of UA yield research undertaken, the five studies which did measure and collect water use data have done so using purpose-built, experimental gardens. The study by Sanjuan-Delmás et al. (2017) was the only one of the five studies to actually calculate the WUE of their experimental rooftop greenhouses, which they defined as, "the water consumed for irrigation per unit of produce" (p. 332). We found no recorded attempt to collect any WUE data on existing urban food gardens, such as those created and managed by home gardeners.

4.2 Theoretical modelling of UA

One alternative approach to physically measuring water use is theoretical modelling using crop water use figures from commercial horticulture. In Italy, Lupia et al. (2015) investigated the water management activities of residential kitchen gardens in Rome. They conducted a theoretical geospatial analysis of various UA land uses (classified as: horticulture, vineyards, olive groves, orchards and mixed crops), together with

commercial irrigation data. Lupia et al. (2015) considered three local water sources (mains, well water and canal water), in combination with two irrigation systems (surface and localised drip irrigation). They concluded that the use of rainwater, coupled with high-efficiency irrigation, could reduce the need for additional water sources, the competition for mains water and the use of potentially contaminated canal water.

In Australia, Ward et al. (2014b) simulated a watering regime considered typical of urban irrigation for a polyculture UA garden. The research was concerned with the potential rise in demand for mains water if UA production increased substantially. When comparing various Australian capital cities (Adelaide, Melbourne, Hobart and Perth), Ward et al. (2014b) found Adelaide to have the highest irrigation water cost for a hypothetical urban food garden delivering approximately 25% self-sufficiency in fruit and vegetables. This high cost was due to a combination of high price and high crop water demand due to low summer rainfall and high evapotranspiration rates. The researchers concluded, "…it is questionable whether garden produce grown in Adelaide could compete with retail prices". More recent research by Ward et al. (2017) used linear programming to optimise the net value of urban agriculture with regards to water applied, area utilised per person, and crop selection to provide a reasonable representation of dietary food groups. Although considering garden area sizes from 1 m2/person to 200 m2/person, the optimal size for water applied per unit area and the net value returned per kL of water applied was between 10 and 20 m2/person (Ward et al. 2017). They concluded that, "even in a climate as dry as Adelaide with its high water prices, a modest food garden growing the right crops can theoretically be highly cost-effective, even with conservative estimates of crop yields and water use." (Ward et al. 2017, p.13).

4.3 Technological advances in automatic irrigation systems

Many existing automatic irrigation systems with built-in controllers to water whole gardens (or sections of gardens) lack flow meters to monitor the volume of water applied. However, irrigation typically occurs according to a specified schedule, meaning that gardeners can calculate the volume of water being applied by such a

system if, for example, they know the number of dripper heads and the volume each head applies (noting, however, that many dripper heads offer a variable flow rate). Alternatively, gardeners could spend time optimising their irrigation system using their household water meter, running one irrigation sub-system at a time without any other water appliances operating, and thus inferring the volume of water applied per hour. Neither option is simple, but if water cost becomes prohibitive to urban gardening these options do at least exist.

Recent improvements in sensor technology for commercial horticultural irrigation systems have had flow-on effects for home garden automatic irrigation systems. Such systems can now use local rainfall tracking, evapotranspiration rates and soil moisture monitoring, together with smarter web and smartphone applications (Cahn et al. 2017). One example of such an improved home watering system is that of the manufacturing company Nymet Pty Ltd. in Adelaide, South Australia. Their 'WaterMe' wireless irrigation controller enables people to not only split their gardens into distinct areas with individual watering regimes, but to also use a linked smartphone application allowing system monitoring and control while away from home (Nymet Pty Ltd 2014). There is an opportunity for the companies producing such automatic irrigation controllers to consider their potential application to assist management of urban food production, in addition to an opportunity for future research to make use of such technology.

4.4 The need for further research

Regardless of the potential watering challenges, a small number of studies have reported UA yields in excess of the average yield rates of commercial horticulture (Stall 1979; Utzinger et al. 1978; Vitiello et al. 2009). However, given that none of these studies measured or reported their garden's water use, it is entirely possible that UA may be less water efficient than traditional horticulture (Ward et al. 2014b). There is currently no scientifically-recorded data on the WUE of existing UA gardens. While there are some data available from the Australian Bureau of Statistics (ABS) (Australian Bureau of Statistics (ABS) 2013), there are no comprehensive data on the water sources and irrigation techniques used specifically for home food production.

Any attempt to calculate, measure and monitor the WUE of UA will have to account for a variety of water sources and irrigation methods. Further research into the water sources, application methods, and WUE of existing UA production is evidently required, especially with the recent rise in the levels of popularity and participation (Wise 2014).

The initial sections of this article have highlighted the lack of empirical UA water use data and water use measurement research available. Consequently, the following sections of this article present South Australia as a case study example to help demonstrate the variety of urban water sources, water prices and irrigation methods available. Four variations on how to calculate the WAE of UA are proposed, before the practical difficulty of measuring UA yield and water use is assessed. To finish, a contemporary South Australian project currently undertaking UA water use measurement of existing home food gardens is introduced.

5. Case Study: Measuring the WUE of UA in South Australia

5.1 Water use in South Australia

The state of South Australia (SA) has mostly arid and semi-arid climates, with the area surrounding the capital city Adelaide receiving an average rainfall of 545 mm per annum (Bureau of Meteorology 2016b). As residents of a dry state, people living in SA have been shown to use 20% less water per capita than the average Australian (Australian Bureau of Statistics (ABS) 2015). It has been suggested that Adelaide has much higher water requirements (per capita) than two of the nearest cities, Melbourne and Hobart in neighbouring states, due to low summer rainfall and high evapotranspiration rates (Ward et al. 2014b).

Extreme weather events across Australia such as droughts, heatwaves, ocean storm surges and severe storms are also becoming more frequent and severe (Hennessy et al. 2007). Such weather events can damage crops and horticultural infrastructure. For example, during late 2016 a severe spring storm demolished and flooded the main commercial market garden area of Adelaide. This destruction temporarily increased the price of fresh produce to as much as double and even triple the standard seasonal prices (Mattsson 2016).

The largest consumer of water in SA is the agriculture industry, which in 2014–2015 used 69% of the state's total water consumption (Australian Bureau of Statistics (ABS) 2015). South Australian agriculture uses groundwater as its main source (44%) of water, while the main source of water for Australian agriculture is from irrigation channels or pipelines (43%). Only a small volume of the water used for agriculture comes from the reticulated mains supply, 1% for Australia and 3% for SA (Australian Bureau of Statistics (ABS) 2016c). Urban residents of SA water their gardens with reticulated mains water, rainwater, recycled-, grey- or storm-water, or bore water (Australian Bureau of Statistics (ABS) 2013). These water sources differ from those used by the agriculture industry, as among urban residents the main source of water for gardening is mains water (69%). Each of these urban water sources and their costs are discussed in further detail below.

5.1.1 Reticulated mains water

The price of mains water for SA residents is split into three tiers according to kilolitre use per quarter annum, with an additional quarterly water supply charge (South Australian Government 2012). In 2011 the SA government announced that the price of mains water was going to increase by 26% to cover the costs of future water infrastructure investments. Such investments included construction of the Adelaide Desalination Plant (ADP), new pipe connections to northern and southern water supplies, and gaining additional temporary water entitlements from the Murray River (South Australian Government 2011). Consequently, by 2011/12 residents were paying an average of $3.96/kL—this average is the tiered usage price combined with the quarterly water supply charge (South Australian Government 2012). Figure 2 displays the widening gap in the average price of mains water between SA households and the Australian average from 2008 to 2015.

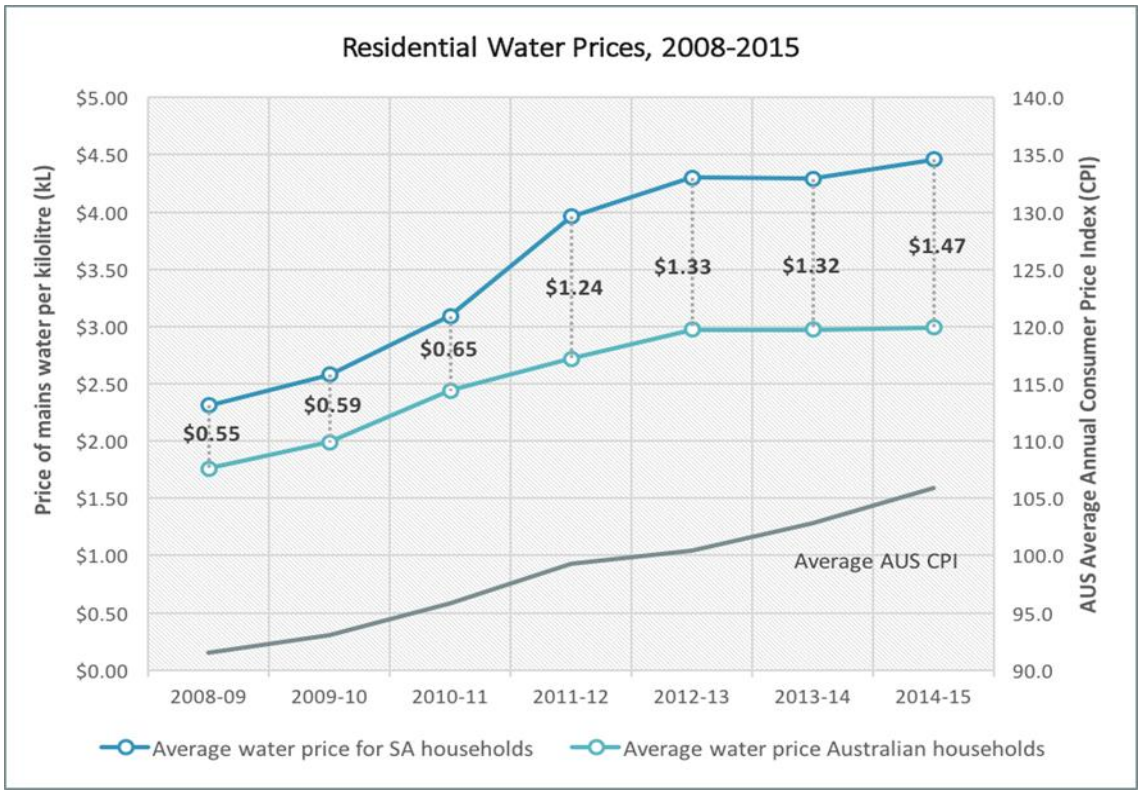


Figure 2. Residential water prices, 2008-2015. The difference in price per kilolitre is shown in the centre data labels. Data sourced from ABS Report Water Account Australia 2014-2015, cat no. 4610.0 (Australian Bureau of Statistics (ABS) 2016a) and the ABS Report Consumer Price Index, Australia, Sep 2016, cat no.6401.0 (Australian Bureau of Statistics (ABS) 2016b).

Since 2013–2014, SA residents have paid the highest price in Australia for urban distributed water (Australian Bureau of Statistics (ABS) 2015). In 2014/15, SA households paid an average of $4.46/kL (again a combination of tiered usage price and quarterly supply charge) (Australian Bureau of Statistics (ABS) 2016b). As of July 2017 residential mains water prices were set at Tier 1 $2.32/kL; Tier 2 $3.30/kL; and Tier 3 $3.58/kL, with a quarterly supply charge of $73.10 (SA Water 2016). A Water Regulatory Determination released by the Essential Services Commission of South Australia (ESCOSA), ensures that until June 2020, the price of mains water cannot rise more than the Consumer Price Index (ESCOSA 2016).

For the SA households using mains water (69%) on their gardens (Australian Bureau of Statistics (ABS) 2013), their outdoor water use is currently inseparable from total residential water use. Each land block typically possesses a single residential water meter to record combined indoor and outdoor water use (Ward et al. 2014b). Urban

food growers using mains water also pay a considerably higher price (Between $2.32/kL and $3.58/kL at 2017/18 prices) than their commercial agriculture counterparts, who pay only $0.09/kL (Australian Bureau of Statistics (ABS) 2016b).

5.1.2 Rainwater

While Adelaide is the driest capital city in Australia, it has the second highest take-up of household rainwater tanks (44.5%) in the country (Australian Bureau of Statistics (ABS) 2013). Regardless of the popularity of rainwater tanks in SA, there has been considerable discussion and disagreement over whether they truly are a financially viable option for household water supply. Research into their levelised cost (cost per kilolitre), cost effectiveness and reliability typically considers multiple variables, including: local rainfall, rainwater tank size, roof catchment area, and whether the water collected will be used only outdoors, or for a combination of outdoor and indoor use (Khastagir et al. 2011; Marchi et al. 2014; Marsden Jacob Associates 2007; Tam et al. 2010).

With such a wide range of roof catchment areas (50–250 m2), tank sizes (1–10 kL), tank lifespans (20–40 years), water usage regimes (outdoor only, indoor and outdoor use) and available rainwater harvest yields (10–156 kL) being used in Australian rainwater research, the conflicting results are unsurprising. As the price of South Australian mains water currently sits in the range of $2.32–$3.58/kL, the levelised cost of collected rainwater can be viewed as a competitive alternative ($1.70–$3.15/kL and $1.70–$2.34/kL respectively (Khastagir et al. 2011; Tam et al. 2010)), as a potential alternative ($2.05–$11.59/kL (Marsden Jacob Associates 2007)), or as an unrealistic alternative water source ($12.08–$21.80/kL (Marchi et al. 2014)), depending on the variables and calculations used.

Separate from roof runoff collected and stored in rainwater tanks, the soil itself has capacity to hold water in the upper layers. While growing food in in-ground garden beds is only one of many different cultivation techniques utilised by urban food growers, it is the one most able to take full advantage of this stored water. In his book, “Out of the Scientist’s Garden”, Stirzaker, Richard (2010) describes his use of simple soil wetter front detectors (small funnels buried in the soil at different depths which

indicate once water seeping through the ground has reached their depth) to monitor soil moisture in different parts of the garden. Stirzaker, Richard (2010) takes this further with his innovative use of the soil as a surrogate rainwater tank. When it rains, and if the rainwater tanks are full, Stirzaker directs the overflow from his tanks to areas of his garden where he knows the soil water is below field capacity. In this way, the water that his existing tanks cannot hold is not wasted and he avoids the expense of additional rainwater tanks. It sounds ideal, but he does explain that such monitoring takes skill, experience and some equipment to apply.

5.1.3 Recycled water: wastewater, greywater and stormwater

Wastewater is effluent processed and treated to reduce its nutrient and organic content. After treatment it can be combined with or used in similar ways as treated stormwater (Government of South Australia 2015). The percentage of wastewater presently being reused is 56% (34% metropolitan and 22% country) (Australian Government Bureau of Meteorology (BOM) 2016). Since 2011 the Christies Beach Wastewater Treatment Plant has supplied over 8000 households in Southern Adelaide with recycled water (SA Water 2016). An example of another type of water re-use is in the Northern Adelaide suburb of Mawson Lakes. In Mawson Lakes, households have separate piping and meters built into their properties to provide treated stormwater, locally known as 'purple piping'. This water comes from the City of Salisbury Aquifer Storage Program. It is mixed with treated wastewater from the SA Bolivar Treatment Works and is intended only for irrigation, gardens or toilet flushing. The price of recycled water is set at 90% of the tier 1 price for mains water, currently $2.08/kL (SA Water 2016).

Greywater is household wastewater from sinks, dishwashers, washing machines, showers and baths. In 2013, 5% of SA households stated their main water source for watering their garden was "greywater" (Australian Bureau of Statistics (ABS) 2013). It is unclear whether this water was diverted and collected via permanent greywater systems, or simply through manual collection by the household. SA Health (2016) require that untreated greywater be used only via subsurface irrigation systems and that the water be applied at a reasonable distance from buildings and all other water

sources. The guidelines also state that, for health reasons, untreated greywater must not be used to water fruit or vegetable plants in South Australia (SA Health et al. 2016).

South Australia is known for its harvesting and reuse of stormwater. There are eight main stormwater collection projects around Adelaide funded in part by the state government's 'Water For Good' initiative. Currently, Adelaide has the capacity to harvest approximately 20 GL per annum (Government of South Australia 2015). This water can replace the use of drinking water for purposes such as greenspace irrigation, toilet flushing and agricultural irrigation. Theoretical research into future water use of UA in the cities of Adelaide, Melbourne, Hobart and Perth by Ward et al. (2014), considered whether surplus stormwater and recycled water currently harvested and treated in these cities could be used for urban food production. The study concluded that the use of such water would considerably improve the cost effectiveness of UA. Ward et al. (2014b) found Adelaide's current surplus of stormwater and recycled water (50 GL) sufficient to provide water for 1.3 million hypothetical optimised 40 m2 food gardens.

5.1.4 Groundwater

Groundwater has a long history of use in South Australia. The South Australian landscape is built upon several layers of porous rock with a high proportion of confined and unconfined aquifers. The water contained in these aquifers travels incredibly slowly over time and is filtered by its passage through layers of rock. Groundwater is one of South Australia's main agricultural water sources, providing 44% of the water for commercial agriculture (ABS, 2016a). In contrast, in 2013 only 2% of SA households stated their main water source for watering their garden was bore or well water (Australian Bureau of Statistics (ABS) 2013). Around Metropolitan Adelaide over 2600 shallow wells, also known as 'backyard bores' have been drilled since 1990 (Barnett et al. 2010). SA Health has guidelines on how to manage, test and use bore water and recommend that bore users regularly get their water tested due to concern over contamination (Environmental Protection Agency - South Australia 2016).

Stormwater collected from winter rains is injected into managed aquifers. This water is recovered at other times of the year when the demand for water is greater (Wahlquist

2008). Stormwater injected into the aquifer becomes classified as 'groundwater' and it is managed as such. Salisbury Aquifer Storage Transfer and Recovery collects stormwater, passes it through a series of reed beds for biofiltration and then pumps the water into a series of aquifers for storage (Wahlquist 2008). As the water passes through the porous rock it is filtered. This filtration results in safe, clean water. Although this water is as clean as recycled wastewater, it is currently restricted for mixing only with non-drinking water. In 2007 the cost of producing water in this way was approximately half of the cost of mains water (Wahlquist 2008).

5.1.5 Desalinated water

Another key element of the South Australian Government's 'Water for Good' initiative was desalination. Construction of the ADP was recommended as a reliable and practical way to provide climate-independent water to the Greater Adelaide region (Government of South Australia 2009). The plant has the capacity to produce 100 GL of desalinated water per annum (Government of South Australia 2015). Since the ADP was completed at the end of 2012, it was used intensively until 2014–2015 when the severe drought of 2003–2012 ended (Bureau of Meteorology 2016a). The operating cost (the cost required to maintain and operate) of water produced by the ADP is $1/kL, making it one of the most expensive fresh water sources in SA (Marchi et al. 2014).

Due in part to some political disagreement over the cost-effectiveness of continuing to run the ADP once SA was out of drought conditions, the ADP was included in the recent Determination Review (ESCOSA 2016). ESCOSA's 2016 Determination concluded that financially there was little difference between continuing to run the plant at minimum capacity and shutting it down to 'standby' and restarting it when needed. The plant currently runs at minimum capacity, producing approximately 8 GL per annum.

5.2 Calculating the WUE of UA

The term "water use efficiency" can be defined in many ways. In order to clarify the term for further use in UA research and evaluation, we propose four equations that can be used to calculate WUE to varying detail. The base equation for "simple" WUE is based on the "Systems Water Use Efficiency" equation practiced by dryland crop

farmers of Northern Australia (Routly 2010). Systems Water Use Efficiency (SWUE) is capable of accounting for single crop or multiple crop and fallow phases, and when applied over consecutive years is less influenced by seasonal variability (Routly 2010). We have adapted SWUE to produce four successive and useful equations.

Each of our four equations can be used in future UA research to provide an understanding of the WUE at study sites. Each equation incorporates area under production and the duration of study time. The important part of these equations is the sum of all water. This includes both applied irrigation and any rain which falls on the area under production over the study time. The Water Footprint Network website defines green water as, "the water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants" (SAB Miller et al. 2009). The total water footprint of a product or crop is made up of green water, blue water ("water that has been sourced from surface or groundwater resources" (SAB Miller et al. 2009)), and grey water ("the amount of fresh water required to assimilate pollutants to meet specific water quality requirements" (SAB Miller et al. 2009)). For example, the global average water footprint of apples is 822 L per 1 kg, of which 68% (559 L) is green water, 16% (132 L) is blue water and 15% (123 L) is grey water (Mekonnen et al. 2011).

Including rainfall allows for fair comparison of UA from different parts of the world. In many places around the world, the WUE of commercial horticulture and agriculture have been improved beyond simple improvements of irrigation systems, crop choices or planting schedules and has reached the point of researching small complex improvements via crop breeding and physiological interventions (Costa et al. 2007; Loveys et al. 2000). There are potentially much simpler mechanisms to improve the WUE of UA. As discussed earlier, UA is a typically polyculture food production and is thus likely to be rife with both under- and over-watering. Measuring both the rainfall and all the water applied via irrigation to a particular area over a set duration of time will account for any possible overwatering, which could be considered as a waste of water, money and time. Discussed below are the advantages and limitations of each equation. In addition to measuring all water (both rainfall and applied irrigation), ideally, we also recommend monitoring changes in soil moisture over the set study

time. Soil moisture can be thought of as "inherited" water, and if not accounted for, studies running short-term experiments in particular could give misleading results. For example, an experiment could begin data collection at the end of Winter, with soil moisture at field capacity, then applies very little irrigation over a Spring growing period and finishes data collection with high yields, low (or even no) irrigation and modest rainfall, but with the soil moisture potentially depleted to almost wilting point. The next crop would require significantly more irrigation to replace the depleted soil moisture.

Suppose a garden achieves a total yield (Y) of all crops produced from a particular area (A) over a set amount of time (T), with total water (W) received by those crops over the same period. It is possible to simply measure water use per unit area per unit time (i.e., W/TA), which could be used to compare between garden watering regimes. However, such a measure does not account for the produce from the garden and hence does not represent 'efficiency' in the sense of output relative to input resources. For this reason, our WUE measures are based on yield (Y) and water use (W), which incorporate area and time implicitly (i.e., larger areas and/or longer periods should both yield more and consume more water).

The first and simplest measure is WUE_{gross} (1), which relates total yield to total water use:

$$WUE_{gross} = \frac{\sum Y}{\sum W} \quad (1)$$

WUE_{gross} crudely accounts for polyculture production through a gross yield aggregation, and allows for basic comparisons among different cultivation techniques and/or irrigation systems. It does not allow for comparisons between individual crops and could become easily distorted if comparing systems producing only heavy- or only light-weight crops. Moreover, by aggregating yields in this way, crops of different value (nutritional or financial) are counted equally by weight. WUE_{gross} is presented as a "better than nothing" approach to water use measurement.

In Equation (2), WUE_k, disaggregates yield (Y_k) into different crop categories (e.g., Vegetables: Leaf/Root/Fruit, Fruits: Tree/Shrub/Cane/Groundcover, Herbs: Leaf/Flower and potentially, Animal Products: Eggs/Meat/Milk/Fish/Honey), with categories denoted by subscript k, and divides by the water applied to each crop category (W_k).

$$WUE_k = \frac{Y_k}{W_k} \quad (2)$$

This categorisation provides the greater level of detail required for polyculture production. Yet its application in practice would be limited by requiring a greater level of precision especially when attempting to measure water applied (rainfall, irrigation and change in soil moisture) for each individual crop type. For example, if one was measuring WUE_k of Vegetable: Leaf crops, then one would also have to ensure that only the area taken up by those Vegetable: Leaf crops, and only the water applied to those crops was accounted for. If studying urban food gardens where the crops are divided by category into geometrically simple rows or beds and irrigated uniformly, this could be feasible, but would become impractical for a more complex polyculture with mixed-planting.

In an effort to identify a simple and practical measurement which accounts for mixed plantings, two additional measures are proposed. The first (3) is "nutritional WUE", WUE_{nut}, which builds on (1) and (2) by introducing a common nutritional unit for aggregation across crop categories:

$$WUE_{nut} = \frac{\sum(Y_k N_k)}{W} \quad (3)$$

Where N_k is the concentration of a nutritional parameter of interest in crop type k, such as energy content in kilojoules (or kilocalories), expressed per kilogram of yield weight. The units of WUE_{nut} are the relevant nutritional quantity (e.g., kilojoules) returned per kL of water used. Other nutritional qualities (for example, grams of protein, or even vitamins, minerals and micronutrients), could be compared in the same way. Incorporating nutritional values provides an opportunity to compare completely diverse polycultures, to examine how water-efficient they are per equivalent dietary

contribution. The practical advantage of WUE_{nut} is that yield weights (Yk) can be easily recorded per crop type, while water can be measured in aggregate for the whole planting. The nutritional contents (Nk) can be determined post-harvest from publicly available nutritional databases (for example, NUTTAB (Food Standards Australia New Zealand 2017) or USDA Food Composition Databases (United States Department of Agriculture (USDA) 2018)).

The final Equation (4) presents "financial WUE", WUE_{fin}, which complements WUE_{nut} by calculating worth in the form of retail value ($) of the total yield.

$$WUE_{fin} = \frac{\sum(Y_k F_k)}{W} \quad (4)$$

Where F_k is the value of crop type k, in the appropriate currency (e.g., AUD$) per kg. For household gardens, retail value (rather than wholesale value) is appropriate, to allow for comparison between what households would have to pay if they purchased the food instead of producing it themselves. As with WUE_{nut}, the only field measurements required for WUE_{fin} are the disaggregated yield weights (Y_k) and aggregate water use (W), while F_k can be determined from retail prices post-harvest. WUE_{fin} returns the efficiency in terms of retail value ($) per kL of water used. Or in turn it can also be divided by the cost of the water itself, resulting in a retail value ($) per water cost ($). Accounting for the cost of water does however become tricky if using any water source other than mains water. The limitations of WUE_{fin} are that the retail value ($) of each individual crop depends on the location of the study, the time of year (seasonal demand), and whether there is any consideration of increased produce value due to it being 'local' or 'organic'. While several past studies have used standard supermarket prices (Algert et al. 2014; Cleveland et al. 1985; Codyre et al. 2014; Stall 1979; Stephens et al. 1980; Utzinger et al. 1978) (mostly the earlier studies), others have used Farmers Market or "Organic" prices to calculate the retail worth of their tracked produce (Algert et al. 2016; Conk 2015; Gittleman et al. 2012; Vitiello et al. 2010; Vitiello et al. 2009). We support the idea of monitoring produce prices from at least two separate sources so an average retail price can be used in any calculations. With regards to "organic" prices, it seems unfair to compare the non-certified (possibly only

semi-organic) grown produce of urban food gardens, with the expensively certified produce of commercial organic growers.

In summary, we appeal to all future UA research to include the following two measurements, in addition to the area under production (A) and the duration of the study (T):

1. Overall water use, *W*, including the relative contributions by rainfall and irrigation, and—if possible—an estimate of change in soil moisture conditions
2. Yield, Y_k, per crop category

These measurements allow the basic WUE_{gross} to be reported, representing a major improvement in UA research. Reporting Y_k values—even without computing WUE_{nut} or WUE_{fin}—would allow other researchers in this space to post-process and compare studies meaningfully.

5.2.1 Demonstrating the WUE of UA equations

To demonstrate the types of scores resulting from these recommended equations, below three of the equations have been applied to the results from Cleveland et al. (1985) (Table 2). Cleveland et al. (1985) collected input and yield data on two in-ground garden beds (77.4 m^2 and 58.3 m^2) located in Tuscon, Arizona USA, producing vegetables for 3 and 2.5 years respectively. Average annual rainfall for the region was low, only 285 mm per annum. Cleveland et al. (1985) were comprehensive in their reporting of results, listing both the yield and value of each individual crop. Nutritional values were not included, but we were able to source these from the Australian NUTTAB database (Food Standards Australia New Zealand 2017).

Table 2. Results from Cleveland et al. [28] used to test WUE_{gross}, WUE_{nut} and WUE_{fin}.

Measurements and Equations		Garden A	Garden B
Area under production (*A*)		77.4 m^2	58.3 m^2
Duration of study (*T*)		3 years (36 months)	2.5 years (30 months)
Water use (kL)	Rain	66.2	41.5
	Irrigation	42.2	45.2
	Total, W (kL)	108.4	86.7
Total values	Total yield, Y (kg)	96.2	134.4
	Total energy, Y_kN_k (kJ)	9,722	10,203
	Total retail value, F_kN_k ($)	154.14	178.32
WUE_{gross} (kg/kL)		0.88	1.55
WUE_{nut} (kJ/kL)		112	271
WUE_{fin} ($/kL)		1.42	2.06

Garden B displays consistently higher WUE than Garden A, due to having produced almost twice the yield per square meter. Without soil moisture data, it is not possible to know the full difference in each garden's endowment of water, although as the study ran over multiple years this is potentially less important. The same crops were grown in both gardens, meaning that the ratio of the two WUE_{gross} values (1.76) was expected to be seen in the Nutritional or Financial WUE; it is interesting to note therefore that Garden B delivered 2.4 times the nutritional energy per kL of water, but only 1.4 times the financial value relative to Garden A. These results highlight the useful additional detail that can be gained from calculating WUE_{nut} and WUE_{fin}.

5.3 Measuring the WUE of UA

Besides the simple measurements of area under production (*A*) and the duration of study time (*T*), the three base components of all four equations include accurate measurement of yield Y_k, area under production, overall water use *W*, and preferably an estimate of change in soil moisture conditions. While measuring the area under production is relatively straightforward, the measurement of yield and applied irrigation are both more complex. As discussed by Pollard et al. (2017) and as touched upon earlier in the PRISMA review, there are three main ways to collect data on UA, (1) Build, manage and collect data on experimental food gardens; (2) Create theoretical models to extrapolate potential values based on commercial yields or small datasets; or (3) Collect data on existing urban food gardens, such as those managed by home-

gardeners. Option 3 is the most likely to provide realistic data, but it is also the most complex approach. Urban food gardens in South Australia, for example are incredibly diverse in their garden sizes, cultivation techniques, gardening approaches and in the gardeners themselves, with different amounts of time and money invested and challenges faced (Pollard et al. 2018). Most of these urban food gardens exist on private property, thus gaining permission to access them becomes another challenge. But once access to these food gardens is available, how does one go about measuring everything that needs to be measured?

5.3.1 Measuring UA yield

There remains indecision about the most suitable unit of measurement of UA yields. Commercial horticulture crops are typically grown separately in rows or bed sections. UA is typically grown as a polyculture with mixed crops including vegetables, herbs and fruits. While the majority of previous UA yield studies have produced a simple combined total yield (in kg or lb) per area (m^2 or ft^2) (Algert et al. 2016; Algert et al. 2014; Cleveland et al. 1985; Codyre et al. 2014; Conk 2015; Conway 2016; Rur 2010; Stall 1979; Utzinger et al. 1978; Vitiello et al. 2010; Vitiello et al. 2009; Zainuddin et al. 2014) (with some subsequent extrapolation of yields to other larger gardens, and some division of harvests into fruit, vegetable or herb categories), two previous UA yield studies have combined the first method with a second method of counting the number of individual crop plants per area (Gittleman et al. 2012; Pourias et al. 2015). This secondary method allows yields from the first gardens weighing all their harvests to provide a yield estimate for the subsequent gardens, although this approach can be cumbersome. Combining total weights does provide a simple figure to use, yet it does not fully allow for comparisons among crops of different weights (for example, herbs vs. root vegetables). As noted in the descriptions of the WUE Equations (3) and (4), different crop types are also likely to have different nutrient contents and retail values. Keita et al. (2016) from the Food and Agriculture Organisation of the United Nations produced a paper attempting to tackle the lack of estimation methodologies suitable for horticulture farmers in Africa, titled, "Measuring area, yield and production of vegetable crops". While their proposed method was intended as a method of surveying all the horticulture farms of a particular region or even country, it did consider a

number of particulars of field-based small-scale horticulture. These particulars include: the type of vegetable crop (leaf, root or fruit), the mode of harvest (single, staggered or successive), and the cultivation technique (on bed or full field) (Keita et al. 2016). Such details are important to document as part of the potential variations in any study of UA.

5.3.2 Measuring applied irrigation

With regards to water, urban residents in SA have the option of using either reticulated mains water, rainwater, recycled or grey water. Although mains water comes at a regulated pressure (as does the recycled water piped to some areas), water from rainwater tanks or grey water from indoor use is supplied at variable pressures and flow rates. Any method of water use measurement should be assessed for suitability depending on the water source. For example, different types of water meters have different tolerances to water temperature, ambient temperature, frost tolerance, water pressure, and flow rate (Husqvarna Australia Pty. Ltd. 2016). Another consideration when attempting to measure UA water use is multiple watering methods. Households may use multiple methods to apply water across their gardens, including watering by hand (using a bucket, hose or watering can), by non-automatic irrigation (with drippers, agricultural pipe, sprayers or sprinklers), or by automatic irrigation on a timer or series of timers (Australian Bureau of Statistics (ABS) 2013). Any study measuring water use needs to account for any possible combination of water sources and watering methods that are potentially present in a single garden. In the earliest study to record water use, Cleveland et al. (1985) measured the water use of two gardens using a standard residential water meter provided by their local utility company. For small volumes of water, they used calibrated buckets. Algert et al. (2016) were the only other study to describe their method of water measurement, also using water meters on dedicated hoses for their participants to measure and log. Urban gardeners who water by hand using a watering can or bucket could easily use calibrated buckets to measure their water use (standard buckets and watering cans commonly have litre increments marked on them). For urban food gardeners who water using a hose, non-automatic irrigation (such as drippers, agricultural pipe,

sprayers or sprinklers), or by automatic irrigation on a timer or series of timers, a water meter is the more practical option.

Due to the inherent diversity of UA production, we strongly recommend future UA research ensures all the basic details of the UA included in a study are adequately reported. Table 3 lists the details we feel should be reported, with some measurement suggestions for yield and applied water use suitable for different garden setups. We feel the inclusion of these details in future research will provide better clarity and greatly simplify comparisons among studies.

Table 3. Recommended UA study details to report and suitable measurement methods

Urban Agriculture Yield Details						
Urban agriculture type:	Home	Community-style	School	Commercial		
Cultivation technique:	In-ground	Raised Bed/ Planter/ Pot	Wicking Bed/ Planter/ Pot	Vertical	Hydro-ponics	Aqua-ponics
Typical planting structure:	Groups / rows of crops		Polyculture		Vertical layering	
Harvest routine:	Single harvest		Staggered harvest		Successive harvest	
Total area under production:	< = 30m^2 Recommend weighing all crop yields from the total area		>31m^2 Recommend using randomly selected quadrats to represent yields of areas with different cultivation techniques			
Measurement calculation	Yield (kg) per no. plants per area (m^2)		Combined yield (kg) per area (m^2)		Yield (kg) per no. plants per vertical area (m^3)	

With three Yield Measurement Calculations and four Applied Water Use Methods, there are 12 possible Water Use Efficiency measurement combinations for Urban Agriculture

Measurement method:	Digital meter	Displacement meter	Timed bucket test	Timed whole system test		
Typical irrigation method:	Manual		Irrigation system		Automatic irrigation system	
Water source details:	Consistent flow and pressure?	Pump	No pump	Treated	Non-treated	"Other"
Typical water source:	Mains	Rain	Grey	Bore / Dam	Recycled / Storm	"Other"
Urban Agriculture Applied Water Use Details						

5.4 The Edible Gardens Project

One such project undertaking field measurement and data collection of UA water use is the Edible Gardens Project. This project was conducted through the Discovery Circle, a citizen science initiative of the University of South Australia. The Edible Gardens project was designed to investigate the productivity and resource efficiency of urban agriculture in South Australia. The project launched in September 2016 and completed data collection as of June 2018. This project received approval from the Human Research Ethics Committee of the University of South Australia on 8 January 2016

(Protocol number 0000034940). It was open to all South Australian home, school and community gardeners over the age of 18. For greater detail about the Edible Gardens Project (both the online survey and the garden data collection) please refer to two earlier publications (Pollard et al. 2017; Pollard et al. 2018). The project involved 2 phases:

1. An online survey collected via SurveyMonkey, which included a combination of both quantitative and qualitative questions, multiple choice and Likert-style scaled questions. From September 2016 to January 2018 401 people responded to the survey. The respondents were asked about their food gardening, including their motivations, experiences, learning sources, challenges, a description of their food garden, estimated setup and monthly costs, estimated weekly time spent, any food preservation or distribution, and what they valued most about growing food. The two survey questions pertinent to this paper were, "*From where is the water used on your food-producing areas sourced? (Please select all that apply)*" and "*How do you usually apply that water? (Please select all that apply)*".

2. Garden data collection: selected participants collected data on their own food producing gardens. They measured and recorded input and yield data for each of their food garden areas: water (source, irrigation method, volume and time), time spent on food gardening-related activities, all costs and their yields (crop type and weight).

5.4.1 Challenges

Designing an approach for the garden data collection was challenging. Selected participants were not just required to measure and record the water use of their whole garden, but to measure the water use of each food 'growing area'. Growing areas were categorised by the cultivation techniques, with options for: in-ground beds, raised beds, pots and planters, fruit trees, vertical gardens, poultry keeping (chickens), poultry keeping (other), aquaponics systems, wicking beds, bee hives and 'other'. The selected participants were questioned about the water source/s for each recorded growing area and the method/s used to apply that water.

The potential difficulty of customising the data collection toolkits (kits containing instructions, examples and tools to assist the participants in measuring and recording data) was first detected in the survey responses. From the 383 responses, five main water sources were identified, with that water being applied via six different types of irrigation methods (Figures 3 and 4).

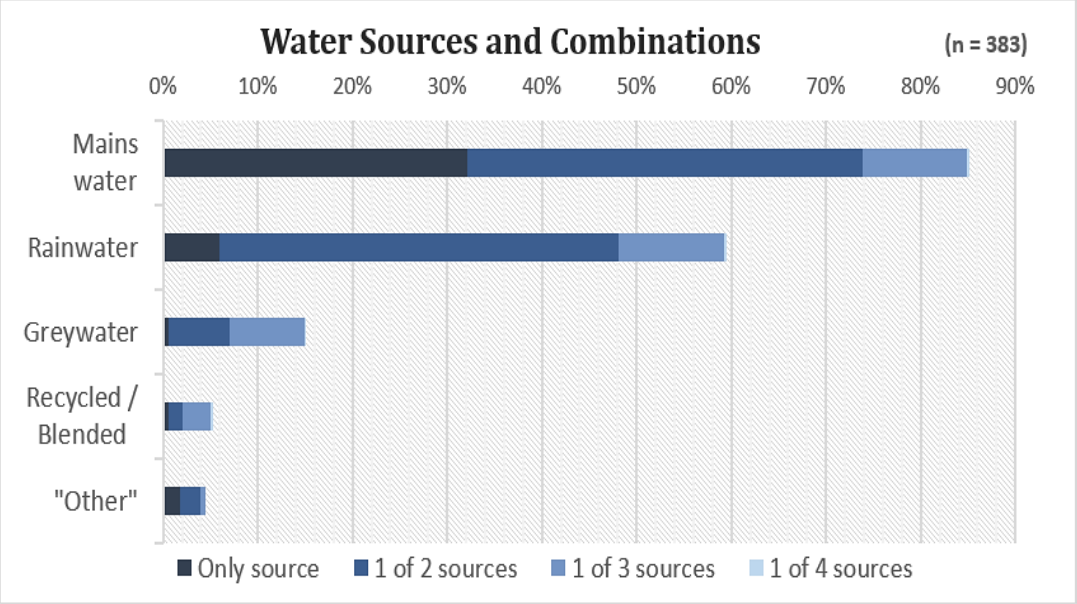


Figure 3. Water sources and combinations used by Edible Gardens Project participants. Note: the sources are not mutually exclusive. "Other" sources mostly referred to the use of bore or dam water.

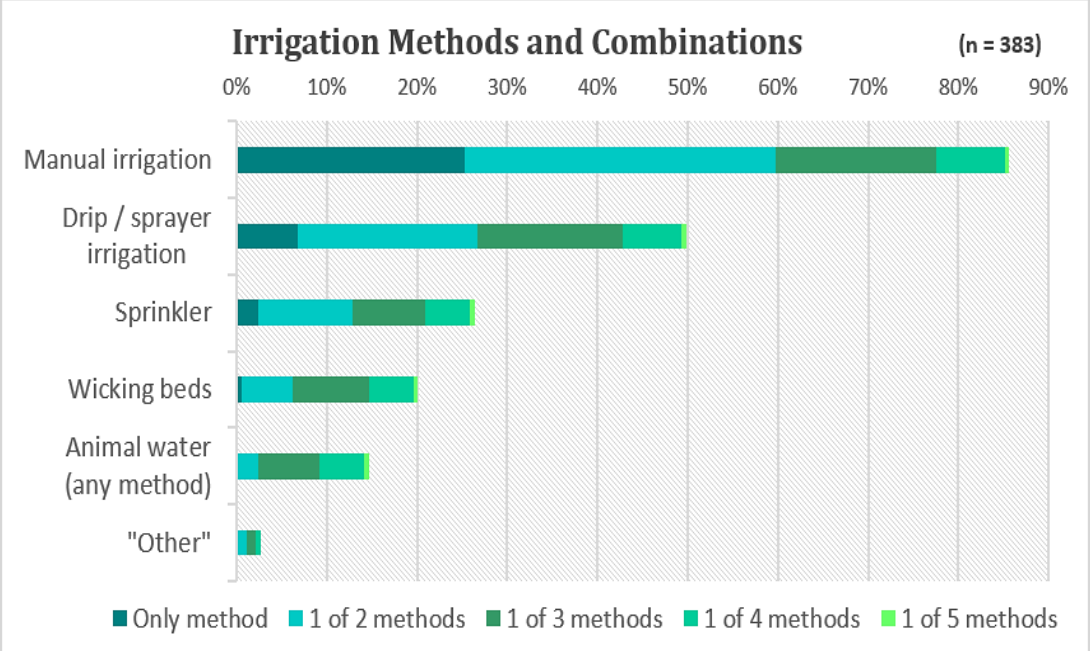


Figure 4. Irrigation methods and combinations used by Edible Gardens Project participants. Note: the methods are not mutually exclusive. "Other" methods mostly refer to grey water piped from washing machines.

Taking that further, 58% of the 383 food gardeners surveyed made use of more than one water source, while 64% use more than one method to apply water. The high number of potential combinations meant any method designed to measure water use would need to be adaptable.

5.4.2 Water meters

Water meters were considered the simplest way to measure the in-field water use of selected food gardens. Several different water meters were available. Such meters ranged in price and type from smaller plastic digital meters costing up to $100 AUS, to large steel residential and agricultural positive displacement water meters costing up to $1000 AUS each. Due to the potential for a considerable number of participants, three brands of the smaller cheaper water meters were selected for further testing.

Two meters of each of the three brands were tested at the facilities of the National Association of Testing Authorities (NATA) accredited Australian Irrigation and Hydraulics Technology Facility at the University of South Australia. The Gardena Water Smart Flow Meter was found to be the more consistently accurate, and suitable for use with mains water. However, overall, inexpensive digital water meters were found to be less accurate at low flow rates and low pressures (such as can be expected from a rainwater tank without a pump). We found that larger positive displacement meters were more accurate when water pressure was low and were therefore more suitable for use with rainwater tanks and other low-flow or low-pressure irrigation systems. The South Australian Water Board regularly test and de-commission Residential Elster Model v100 water meters. They were available in sufficient numbers to use and were able to be fitted with reducers and adaptors to suit any irrigation system.

5.4.3 Project Expectations

The Edible Gardens Project had 42 registered urban food gardeners with 119 individual growing areas, who entered water use data into the projects online data collection system. Some participants collected up to 15 months of water use data on their food gardens, and one pilot participant collected over 24 months of water use data on two wicking beds. The project aimed to collect a minimum of six months water

use data from each registered participant. The assembled data is a collection of seasonal urban food production water use data relevant to specific water sources, irrigation methods and cultivation techniques. Analysis of the data is ongoing and it is the intention of the authors to publish all project data.

5.5 The Utility of UA

Conjecture and healthy scepticism remain around the real or potential contribution of UA to the global food supply. There is concern over the lack of field-based quantitative data (Pourias et al. 2015; Taylor et al. 2013; Ward et al. 2014a; Wise 2014), highly variable reported yields (Algert et al. 2014; Codyre et al. 2014; Pourias et al. 2015; Zainuddin et al. 2014) and ambiguous global estimates of productive contribution (Armar-Klemesu 2000). And yet UA is a widespread and popular activity. In Australia, more than half the population is estimated to be engaged in growing some of their own food (Wise 2014). There are 50 community gardens in South Australia alone (Australian City Farms & Community Gardens Network 2014) and an increasing number of schools creating food gardens to support hands-on learning (Stephanie Alexander Kitchen Garden Foundation 2014). There are small UA businesses growing food and providing services, including Wagtail Urban Farm (Wiseman et al. 2014), Willunga Creek Village Greens, the Adelaide Bee Sanctuary (Adelaide Bee Sanctuary 2018), the Jetty Food Store Co-op (Schmitz 2018) and two different kinds of food sharing, locating and selling networks: GrowFree (Barker 2018) and RipeNearMe (Martin et al. 2018). UA is seen by some as a sort of new-age agrarian livelihood, with the development of practical growing guides to help support those wanting to get into commercial UA. Examples include, guides to SPIN Farming (small plot intensive) (Stone 2018), the deep-organic techniques of Eliot Coleman (Coleman 2009) and the low-tech, high yielding methods practised by Jean-Martin Fortier (Fortier 2014).

In the context of widespread promotion of UA, it is crucial to understand the efficiency and cost-effectiveness of water use in areas with such a large discrepancy in the cost of mains water, in order to assess the extent to which UA has a role to play in our food systems beyond a discretionary or hobby activity. From a water perspective and particularly in regions of lower annual rainfall, the urban food producers depending

on reticulated mains water for their main water source can be at an immediate cost disadvantage compared to their commercial counterparts. As discussed earlier, the price of mains water in South Australia is between $2.32/kL and $3.58/kL, while commercial growers pay only $0.09/kL. Yet this is not necessarily an insurmountable obstacle. The logical next step would be to consider alternative water sources available for urban food production. Rainwater was the second most popular water source of the EG survey respondents however, collection and storage of rainwater is limited by catchment area, rainwater tank size/s and the volume and timing of available rainfall. Consequently, it remains difficult to confirm the levelised cost of rainwater to use in comparable calculations of cost. Other available South Australian water sources include greywater, recycled-, blended- or storm-water, and the occasional backyard-bore or dam. In their paper on the water use implications of an increased uptake of UA in cities, Ward et al. (2014b) calculated that a hypothetical urban food garden providing roughly 25% of the required fruits and vegetables per average household would increase that household's water use by 20–50%. Looking beyond mains and rainwater, Ward et al. (2014b) concluded that the 2014 surplus of 51 GL/year of Adelaide recycled water which at the time was being discharged into the ocean, would, "(if) ignoring issues of distribution… … theoretically be sufficient to irrigate the equivalent of 1.3 million of (the) hypothetical food gardens". As demonstrated by Stirzaker in his book (Stirzaker, Richard 2010), it is up to each household to increase their understanding of water in the garden and develop the potential to collect, apply and monitor water in creative ways.

6. Conclusion

Our extensive systematic review of WUE and measurement in UA, and the consideration of water use data in UA studies of productivity, economic value and full life-cycle or environmental assessments, confirms that there is an increasing level of interest in this type of UA research. However, it remains that only 30 articles focussed on this type of research were identified in the 43 years from 1975 to 2018, eight of which were review papers. Only five studies were found which actively collected some form of water use data, yet all of these were conducted on purpose-built experimental UA (Algert et al. 2016; Cleveland et al. 1985; Richards et al. 2015; Sanjuan-Delmás et al.

2017; Sanyé-Mengual et al. 2015). No single study was identified which collected and published WUE data on existing UA, such as on the dominant form of UA in Australia—home food gardens.

The future challenges of climate change and constrained resources such as fresh water, fertiliser and fertile topsoil, are likely to both increase the price of food and are leading to increased interest in UA. There are claims that UA can assist in supplementing the food security of towns and cities in the future. Currently there is a lack of existing rigorous scientific data to support these claims. If UA is to be a reliable part of future food plans, then the full costs and resource requirements of its production must be taken into consideration.

This paper acknowledges the challenging aspects of assessing the input requirements, resource efficiency and productivity of UA. One major factor in such assessments is water. UA water use has been regularly overlooked by past research. The absence of UA water use data points to a need for future UA research to make a better attempt to measure and calculate the WUE of UA, preferably using one of the two more detailed WUE equations (WUE_{nut} and WUE_{fin}) proposed in this paper. At the very least, rainfall and irrigation should both be reported, along with disaggregated yields per crop type. Certain practicalities must be taken into consideration, namely garden placement, cultivation techniques, water sources and irrigation methods. A combination of water meters tailored to fit all types of irrigation systems appears to provide the best capacity for water use measurement. One existing project working towards the collection of UA water use data is the Edible Gardens project. Designing a method for participants to measure the water use of their different 'growing areas' (areas categorised by cultivation technique) was challenging.

The collection of UA water use and yield data will provide a firm basis for further evaluation of how much water is being applied to UA gardens, their WUE and the comparison of different irrigation and cultivation techniques. It will also assist with calculation of the cost of water applied—thereby allowing more comprehensive economic evaluations of UA and assisting in its further optimisation. Only once these practical evaluations of existing UA production have been completed, will we have a

clearer understanding of what UA currently contributes to our society and what future prospects may be possible.

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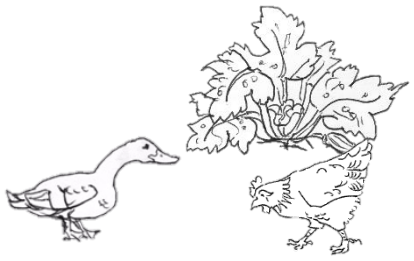
4 The Sustainability and Diversity of Urban Agriculture



Overview

This chapter explores the place of urban agriculture in our collective future visions of 'sustainable cities'. Here sustainability is defined as, "the ability of the earth's various natural systems and human cultural systems and economies to survive and adapt to changing environmental conditions indefinitely." (Miller et al. 2008). Theoretically at least, urban agriculture has the potential in certain circumstances to influence all three pillars of sustainability: social, environmental and economic. This paper focuses on the practical, physical and economic elements of home food gardens and their potential influence on the economic sustainability of urban agriculture. The paucity of data on the complete input costs of home food gardens is emphasised, before the overall potential contribution of urban agriculture – and whether it is a 'net saving' or a 'net cost' – to our sustainable future is questioned.

This paper presents the first of the data collected by the Edible Gardens online survey. It begins by detailing the inherent diversity in the garden setups, the inputs, and the food gardeners themselves. Also displayed is a figure of the statistically typical urban food garden (developed from the median category results) to illustrate the present-day home food garden in South Australia. When the survey gardens were compared with a theoretical optimised garden model, the key differences included the prominence of fruit trees, the value of time and the likelihood of yield variation in real food gardens. Further research is therefore recommended for theoretical garden models to be able to incorporate more realistic yield data, in addition to including time and both setup and ongoing costs. The top challenges experienced by the EG survey respondents are

reported and compared with previous research. The final section of the paper assesses the implications of economic sustainability of home food gardens. Interestingly, although the majority of respondents appeared to be in a position of relative socio-economic advantage, cost was still one of the top five reported challenges. Measurement of the full costs of different gardens would allow better predictions of whether growing food can save households money and under what circumstances.

This chapter contributes to research objectives:

1. *Assess the scope of previous urban agriculture measurement research in developed countries and identify gaps in data and measurement procedures.*

2. *Develop and implement a novel approach to enable widespread measurement of urban agriculture input and yield data on existing urban food gardens.*

3. *Clean, manage and analyse collected data from both Phase 1 and 2 to gain an in-depth understanding of current urban food gardens in South Australia.*

4. *Respect and acknowledge the reciprocal relationship with the 'citizen scientists' (survey respondents and selected phase 2 participants) who contributed data to the Edible Gardens project.*

This paper was published in the journal Sustainability in 2018 (Paper 3). The manuscript was co-authored by supervisors Dr James Ward and Dr Philip Roetman from the University of South Australia.

Author Contributions: G.P., J.W., and P.R. conceived of and designed the EG project and survey; G.P. analysed the data; and G.P., J.W., and P.R. wrote the paper.

The format of this paper has been altered for consistency with the rest of the thesis.

Paper 3: Typically diverse: The nature of urban agriculture in South Australia

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Abstract

In our visions of the future, urban agriculture has long been considered an integral part of the 'sustainable city'. Yet urban agriculture is an incredibly diverse and variable field of study, and many practical aspects remain overlooked and understudied. This paper explores the economic sustainability of urban agriculture by focusing on the physical, practical, and economic aspects of home food gardens in South Australia. New data from the Edible Gardens project online survey is presented on a broad range of current garden setups, including a figure illustrating the statistically typical South Australian food garden. The differences between the survey data and a recent optimized garden model further highlight the gap in knowledge regarding existing home food gardens. With regard to the financial accessibility and economic sustainability of home food gardens, there is also still much more work to be done. Although saving money is a top motivation, with many survey respondents believing that they do succeed in saving money, it remains to be seen whether their current gardening practices support this aspiration. Measurement of the full costs of different gardens would allow for better predictions of whether growing food can save household's money and under what circumstances.

Keywords: urban agriculture; urban gardening; economic sustainability; optimization; challenges; measurement; resource efficiency

1. Introduction

In our visions of the future, urban agriculture has long been considered an integral part of the 'sustainable city'. It is anticipated that urban agriculture will contribute to food security, city resilience, conservation of resources, and recycling of urban wastes, and that urban planning could one day transform our cities into farms (Burton et al. 2013; Deelstra et al. 2000; Farrell 2017; Pearson et al. 2010; Pires 2013; Smit et al. 1992). There are many different forms of urban agriculture (UA): home food gardens, school gardens, collective or community gardens, and urban farms. The focus of this paper is home food gardens in developed countries. As the most dominant form of UA in the developed world (Butterfield 2009; Taylor et al. 2013; Wise 2014), home food gardens have the potential to greatly contribute to future sustainability.

Many of the practical aspects of UA remain overlooked and understudied (Conway et al. 2014; Gray et al. 2014; Mok et al. 2014; Pollard et al. 2017; Taylor et al. 2013; Ward et al. 2014a). In relation to home food gardens, such practical aspects include the different production methods or gardening approaches used, the productivity of these different methods, their water efficiency, the full costs involved, and their main benefits and challenges. Home food gardens are also widely spread across urban areas; they are on private property—often hidden behind fences or in backyards—and there is great diversity in the ways people grow food. These characteristics all contribute to the difficulty of conducting research on home food gardens (Conway et al. 2014; Kortright et al. 2011; Taylor et al. 2013).

The research that has been conducted on UA has often not been able to, or has refrained from, measuring labour, full costs, and water use. As discussed in detail by Pollard et al. (2017), early research into the economic viability and productivity of UA focused on collecting data from a small number of purpose-built experimental gardens (Cleveland et al. 1985; Stall 1979; Stephens et al. 1980; Utzinger et al. 1978). These early studies did measure time and, to some extent, costs, but only one study measured water use. Indeed, to this day, Cleveland et al. (1985) remain the only in-field UA study to have fully accounted for water use. This is particularly concerning as water scarcity increases and water becomes costlier to both treat and supply. More recent research has measured yields from a greater number of community gardens (Algert et al. 2014; Gittleman et al. 2012; Pourias et al. 2015; Vitiello et al. 2010; Vitiello et al. 2009) and existing home food gardens (Codyre et al. 2014; Conk 2015; Zainuddin et al. 2014). The main focus of these recent studies was yield and the retail value of the crops grown. Water was not measured at all, and only Codyre et al. (2014) measured labour and costs. Yet despite the lack of verification, 'growing your own' is still commonly advocated in popular literature as a way for households to reduce their cost of living by saving money on their food bills (Doiron 2009; French 2009; West 2018).

In addition to the need to consider labour, costs, and water as inputs in their own right, we must also consider the impact of these inputs on the economic sustainability of home food gardens. If the setup or maintenance costs of an urban food garden prove

too great a barrier to households wanting to save money, then growing food should no longer be promoted in such a way. Moreover, if UA is intended to be an integral part of our vision for the sustainable city, then it is imperative to know whether the inclusion of UA in this vision adds a net savings or a net cost. Certain garden setups may lend themselves to higher productivity, higher water efficiency, lower labour input, and/or lower costs than others. But without further research into the variety and effectiveness of the myriad garden setups currently used in home food gardens, no recommendations can be made.

In the absence of data, theoretical models can simulate UA and predict potential yields. Because of the lack of in-field UA data available, these models are either calculated based on extrapolated results from small data sets (Dewaelheyns et al. 2014) or by using commercial horticulture crop data (Colasanti et al. 2010). Consequently, theoretical models may overestimate garden productivity (Ackerman 2011). One recent example of a theoretical model is by Ward and Symons (Ward et al. 2017). Their model was based on commercial data. Time spent was assumed to be discretionary (and therefore not quantified), and water and fertilizer were the only costs included. The collection of new data on the practical aspects (especially time and money) of existing home food gardens would not only provide a more realistic basis for further theoretical UA models, but would also make a considerable contribution to our understanding of the economic sustainability of home food gardens.

The objective of this paper is to explore the economic sustainability of UA by focusing on the physical, practical, and economic aspects of home food gardens in South Australia, as reported by the gardeners themselves. Similar to other countries such as the United States, the United Kingdom, and Germany, Australia is a place of high food security and relatively low food prices. In overall food security, Australia is ranked fifth out of the 113 countries listed by the Global Food Security Index (The Economist Intelligence Unit 2017). With regards to food affordability, food constitutes only 10% of total consumer expenditure in Australia—a percentage comparable to those in the United Kingdom (8%), Germany (10%), and Japan (14%) (United States Department of Agriculture (USDA) 2017). South Australia is presented as an interesting case study

because of its dry climate (receiving an average of 545 mm of rainfall per annum and containing the driest capital city in Australia), high evapotranspiration rates, high price of mains water (currently a tiered mains water price between AUS$2.27/kL–AUS$3.51/kL), and large proportion of the population engaged in food production (59%) (Australian Bureau of Statistics (ABS) 2015; Bureau of Meteorology 2016; SA Water 2016; Ward et al. 2017; Ward et al. 2014b; Wise 2014). New data from an online survey is presented on the area under production, gardening approaches, production methods, estimated inputs, and the challenges faced by urban gardeners. A figure of the statistically typical urban food garden (as based on the median of the category results) is presented to illustrate the present-day home food garden in South Australia. Ward and Symons's (2017) recent theoretical model is reviewed in light of the survey data. The discussion then turns to what these results mean for households wishing to save money by growing some of their own food as well as recommendations for future research.

2. Materials and Methods

In September 2016, the "Edible Gardens" project was launched by the Discovery Circle, an initiative that runs citizen science projects, based at the University of South Australia. Edible Gardens (EG) is a citizen science project aimed to investigate the resource efficiency, productivity, and social value of UA in South Australia. An online survey collected a range of data on South Australian home food gardens and was open to all gardeners over the age of 18 within the state. Included in the survey were questions on basic demographics, motivations, challenges or barriers experienced, and practical aspects of the food gardens, such as size, production method, typical crops, water source/s, irrigation method/s, and estimated time and money spent. The survey was designed using the online survey tool SurveyMonkey. These data provides a snapshot of how people are approaching growing food and the diversity of philosophies and activities that exemplify urban food production in South Australia. There is no way to test fully the veracity of these data; however, this survey method is consistent with previous work, such as that by Wise (2014). This project received approval from the Human Research Ethics Committee of the University of South Australia on 8 January 2016 (Protocol number 0000034940).

The survey was promoted on the Discovery Circle website and Facebook page and via other print materials and press releases from the project sponsors: the University of South Australia; the Department of Environment, Water and Natural Resources; the Adelaide and Mount Lofty Ranges Natural Resources Management Board; the City of Salisbury; and the City of Marion. A large number of project postcards were also distributed around South Australia to libraries, garden centres, community gardens, community centres, farmer's markets, and other relevant businesses. During the survey period (September 2016 to January 2018) 379 people responded to the survey. The survey results were analysed using a combination of Microsoft Excel, IBM's SPSS Statistics Software, QSR NVivo Qualitative Analysis Software, and R 3.4.0 (R Core Team 2017) using the NETWORK package (Butts 2008, 2015).

3. Results

The results are divided into five categories: demographics, gardening background, physical garden elements, garden inputs, and a theoretical comparison. These categories cover all of the survey questions relating to the practical aspects of the respondents' urban food gardens (for the full list of these questions, please refer to the Supplementary materials). The results of this study are intended to provide a broad foundation of survey data. It is the intention of the authors to conduct a follow-up study based on in-field garden inputs (such as labour per activity, water use, and costs) and outputs (such as individual crop yields). Therefore, this survey focused more on gardening methods, rather than crop types, as a basis for future comparison of perception and measured reality. Additional results collected by the EG survey, including motivations, social learning sources, food preservation methods, food distribution frequency and recipients, and the value of growing food will be presented in a separate paper.

3.1 Demographics

The Edible Gardens survey respondents ranged in age from 18 to 81+, with a median age-range of 41–50. The majority of the respondents were women (77% female: 22% male: 1% indeterminate/unspecified). The median number of people living in the household was three, with 34% of households having primary school age or younger children present and 16% having at least one person over the age of 65 present. Postcode data allowed us to map and classify the respondents according to whether they lived inside (82%) or outside (18%) the boundary of metropolitan Adelaide. Figure 1 displays the mapped postcodes across and close to metropolitan Adelaide, the boundaries of which are coloured purple on the map. There are 24 additional survey postcodes from across wider South Australia that are not visible in Figure 1.

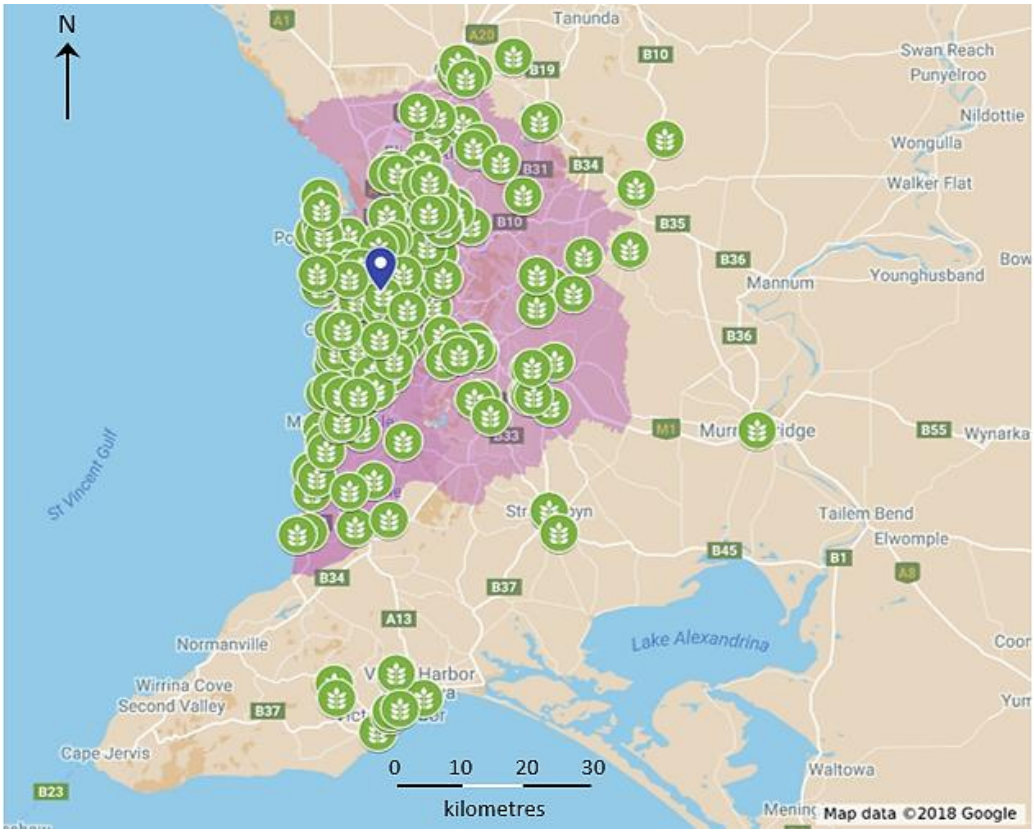

Figure 1. The Google MyMap of the distribution of the Edible Gardens survey responses. Each green marker shows the location of a unique survey postcode. The bounded region is the Adelaide metropolitan area and the blue marker pinpoints the centre of Adelaide Central Business District (34°55′43″ S, 138°35′60″ E).

A number of questions were related to relative socio-economic advantage and were used to contextualize the EG survey participant group within the broader South Australian community. Education levels suggested that our respondents were, on average, substantially more educated than the general population with 35% holding a bachelor's degree and 31% holding a postgraduate degree. By comparison, 14% of South Australians hold a bachelor's degree and only 4% hold a postgraduate degree (Australian Bureau of Statistics (ABS) 2016b). Using the survey respondents' postcodes as a proxy for location, we were able to examine their distribution using Australia's Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) rankings. Figure 2 shows the distribution of postcodes of the EG respondents as compared to the rankings for the whole of South Australia. The majority of the EG respondents' postcode index rankings (59%) were above the fifth decile, compared with only 39% of the total South Australian rankings. In particular, the highest two deciles were substantially over-represented and the lowest two deciles were substantially under-represented in our survey respondents (as measured by their postcode) relative to the general population.

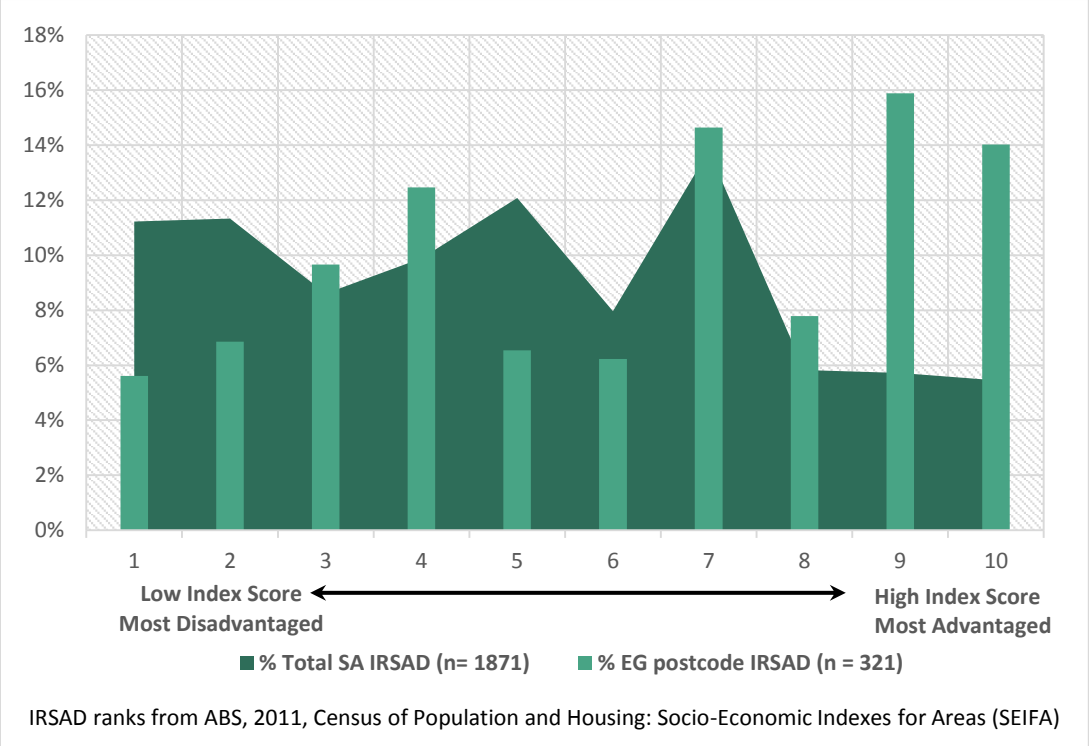

Figure 2. Comparison of the Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) rankings of the Edible Gardens survey postcodes to the rankings of all South Australian postcodes.

Home ownership (defined as either owning a home outright or having a mortgage) was high at 85%. Of those remaining, 11% were renting and 4% had other situations. There were statistically significant differences (see Table 1) between the home owners and home renters, in that home owners had larger food gardens (U = 6990.5, $n1$ = 270, $n2$ = 35, p = 0.001), spent more money setting up their food gardens (U = 4875, $n1$ = 241, $n2$ = 28, p = 0.001), had higher IRSAD rankings (U = 5668, $n1$ = 268, $n2$ = 35, p = 0.043), and had less of a desire to save money by growing food (U = 3592, $n1$ = 266, $n2$ = 35, p = 0.021). The difference between the home owners and home renters and their desire to save money by growing food (Table 1) was particularly interesting. The same comparison is presented for the two highest and two lowest IRSAD deciles (noting that this uses the respondents' postcode as a proxy). Interestingly, however, no significant difference was found in their perceptions of how much of their weekly fruit and vegetable budget they believed they had actually saved.

Table 1. Comparison of responses to the statement "I produce food to save money": home owners vs home renters; and lowest 2 Edible Gardens postcode ranks of Index of Relative Socio-economic Advantage and Disadvantage vs highest 2 Edible Gardens postcode ranks of Index of Relative Socio-economic Advantage and Disadvantage.

Responses	Home Owners (n = 278)	Home Renters (n = 36)	Lowest 2 IRSAD Scores (n = 39)	Highest 2 IRSAD Scores (n = 76)
Strongly Disagree	**2%**	**3%**	**3%**	**3%**
Disagree	**12%**	**8%**	**8%**	**14%**
Neutral	**30%**	**19%**	**15%**	**32%**
Agree	**42%**	**33%**	**49%**	**41%**
Strongly Agree	**14%**	**36%**	**26%**	**11%**

3.2 Gardening Background and Approaches

Food gardening experience was categorized as follows: 'Less than 1 year', '1–5 years', '6–10 years', and '11+ years'. The median response was 6–10 years. Although there was a weak positive correlation between the age of the respondents and their years of gardening experience (Spearman correlation: r_s = 0.357, n = 332, p = 0.001), this was not true for everyone. The 29 gardeners who reported having 'less than 1 year' of experience ranged in age from 18 to 60 years, and the 116 gardeners who reported having '1–5 years' of experience ranged in age from 21 to 80 years. With regards to

gardening consistency, 62% of the respondents reported growing food 'all through the year', while 18% grew "on and off again" and 14% grew food 'seasonally'.

In an attempt to build up a picture of the 'look' and 'feel' of food gardens in South Australia, gardening approaches were categorized differently from production methods. The list of production methods began as a simple list of different physical methods to grow food; however, there was a need to be able to clearly identify urban livestock as they require specific physical setups. Additionally, fruit trees were identified as an interesting crop/form of food production—one with the potential to grow large volumes of food without too much effort on the part of the gardener. As fruit trees can be grown in in-ground beds, raised beds, pots, or even wicking beds, they were added as an individual production method for easy identification.

Gardening approaches were categorized as the more philosophical approaches with which gardeners may identify. Ten different gardening approaches were listed (based on common approaches used in South Australia and those mentioned previously in the literature (Rur 2010; Zainuddin et al. 2014)) and survey respondents were asked to select all the approaches they used (Figure 3). This question was included as different gardening approaches are commonly advocated as ways to improve a garden and are thought to influence many of the practical aspects of UA; for example, organic gardening may require fewer pesticides, and how adding compost can improve the water retention of the soil.

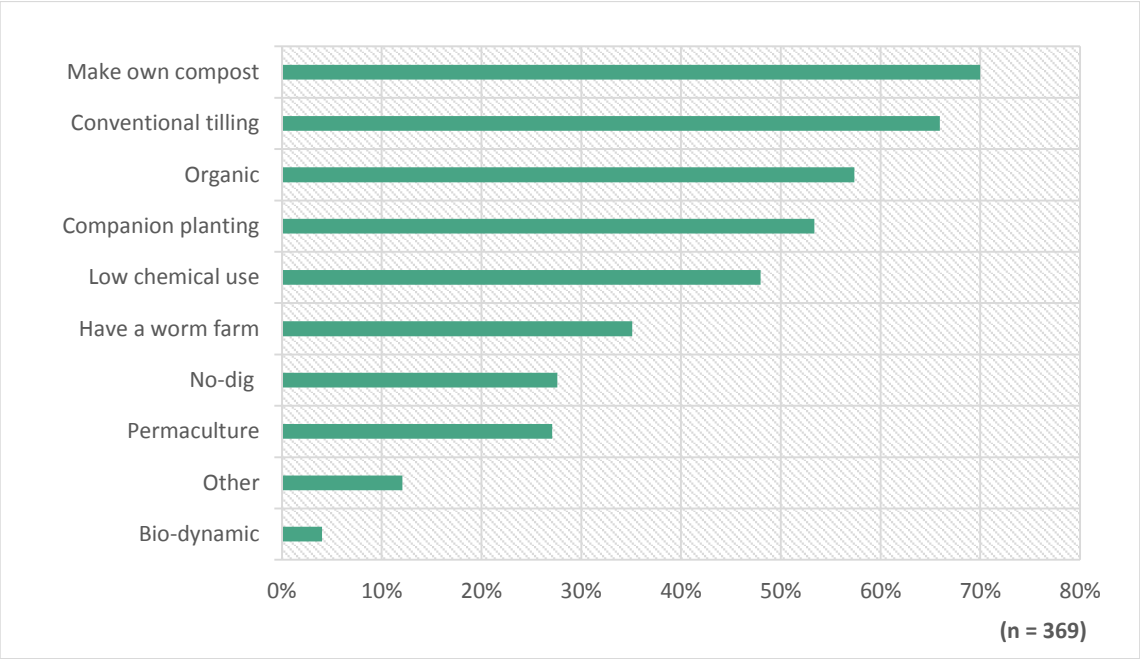

Figure 3. Gardening approaches practiced by the Edible Gardens survey respondents. These approaches are not mutually exclusive.

The median number of gardening approaches with which the respondents identified was four. The top five were composting (70%), conventional digging and tilling (66%), organic gardening (57%), companion planting (53%), and low use of chemical fertilizers and pesticides (48%). There were stronger relationships between certain gardening approaches than between others; for example, respondents who used conventional digging and tilling were more likely to also use a low amount of chemical fertilizers and pesticides (78%), yet they were less likely to use no-dig gardening (38%) or permaculture (45%). Whereas respondents who used a biodynamic approach were more likely to make their own compost (93%), use an organic approach (87%), utilize companion planting (73%), and they were less likely to use a low amount of chemical fertilizers and pesticides (33%).

The challenges of growing food in urban areas were split into two questions. First, respondents were asked to list the top three things that delayed or challenged them when they initially began to grow food. Then, they were asked whether there was anything currently making it difficult for them to continue growing food, and if they responded "yes" (as 61% did), they were asked to describe those current challenges (Table 2).

Table 2. Comparison of initial and current challenges to growing food in urban areas. In both questions, each respondent was given the opportunity to identify multiple challenges.

Initial challenges (*n* = 904)	%	Current challenges (*n* = 272)	%
1 Lack of time	**50**	**1 Lack of time**	**28**
2 Unsuitable conditions	**36**	**2 Unsuitable conditions**	**21**
3 Lack of knowledge	**28**	**3 Water issues**	**12**
4 Lack of space	**25**	**4 Livestock, pet, or pest issues**	**12**
5 Cost	**20**	**5 Physical or health issues**	**11**
6 Water issues	**17**	**6 Lack of space**	**8**
Is there currently anything that makes it difficult for you to continue to grow food? **'Yes' = 61%, 'No' = 38% (*n* = 376)**			

3. 4 Physical Elements of the Food Gardens

The physical elements of the respondents' food gardens included the area under production, the types of growing areas, and the total number of growing areas. The total area under production was categorized as follows: tiny (<4 m^2 (7%)), small (5–15 m^2 (28%)), medium (16–20 m^2 (28%)), large (31–50 m^2 (16%)), and huge (51+ m^2 (16%)) (see Figure S1). The median size under production was medium (16–20 m^2). The total area under production did not refer to the size of the entire garden, but purely to the space dedicated to food production.

A wide variety of production methods were being used (Figure 4). Fruit trees were the most common method (84%) followed by pots and planters (74%), in-ground beds (70%), raised beds (61%), chickens (39%), wicking beds (21%), bee hives (8%), other production methods (7%), vertical gardens (7%), other poultry (5%), and aquaponics (4%). As shown in Figure 5, the strength of the relationship between the different production methods varied. The stronger the connecting line, the greater the likelihood that both production methods were present together in a single food garden. The median number of production methods used was four. The majority of respondents (68%) were using either three, four, or five different production methods simultaneously in their food gardens. The production methods could be grouped according to the number of other production methods likely to also be present in that same garden. In-ground beds, raised beds, pots and planters, and fruit trees were all more than 50% likely to be present with three other production methods. Chickens were more than 50% likely to be present with four other production methods. Vertical

gardens, other poultry, wicking beds, and bees were all more than 50% likely to be present with five other production methods, and an aquaponics system was more than 50% likely to be present with more than 6 other production methods. The number of food producing areas ranged from 1 to 20, with four being the median number of areas.

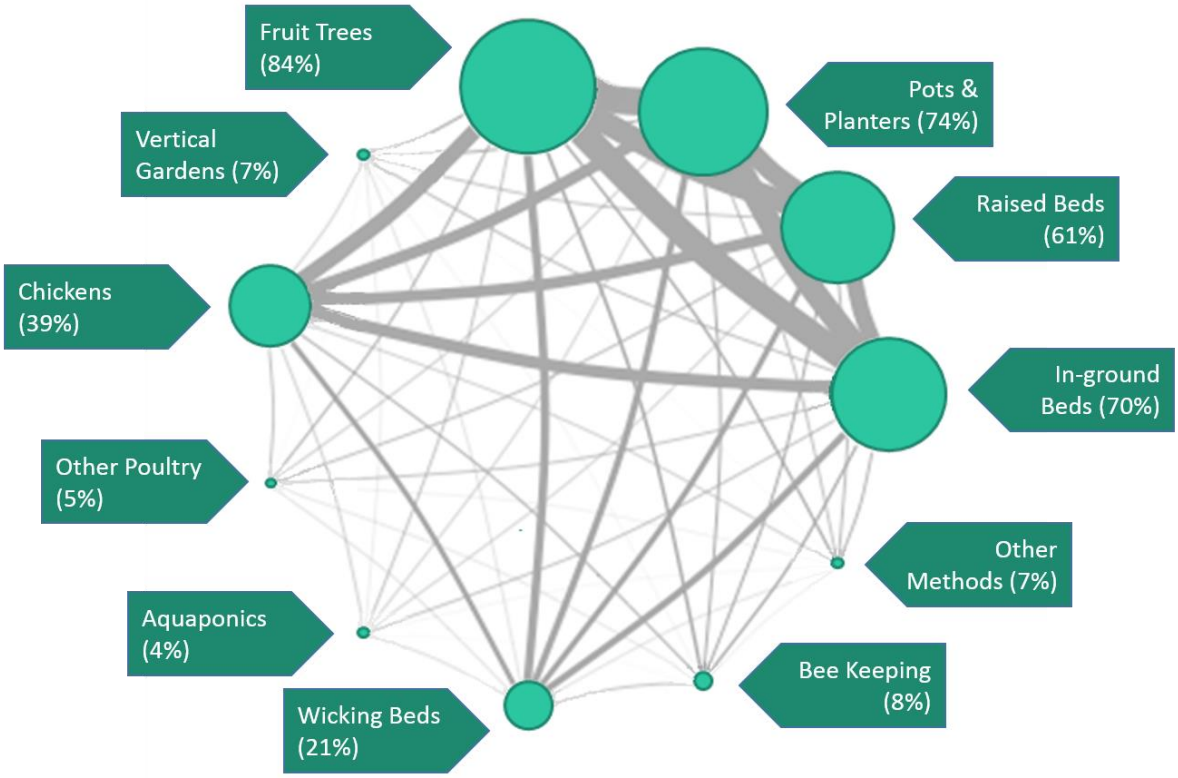

Figure 4. A weighted relationship network of production methods. The size of the circles represents the percentage uptake of the production methods by the Edible Garden (EG) survey respondents. The thickness of the connecting lines represents the strength of the relationship between the two production methods, as defined by the likelihood of both being present in a single garden.

3.5 Garden Inputs

The main garden inputs about which the respondents were asked included time, water, and money. The survey respondents estimated the time spent per week on their food gardens, ranging from less than one hour to more than 20 hours (see Supplementary Figure S2). The most common category of time spent per week was 1–5 hours (55%), and the median was four hours. Statistically, there was no difference between the hours spent by men and women ($U = 4{,}107.5$, $n_1 = 199$, $n_2 = 50$, $p = 0.056$).

Some children (less than 18 years of age) did help out in the food gardens, although generally for only one hour per week (median = 1 h, range = <1–10 hours).

As reported by Pollard et al. (2018), the survey respondents reported a range of water sources, including mains, rainwater, grey water, and recycled/blended water, as well as 'other' sources. Respondents dispensed that water using a variety of irrigation methods, including manual irrigation (via hose, watering can, or bucket), drip irrigation, sprinklers, wicking beds, and any method of providing water for animals, as well as 'other' methods. Both the water source and irrigation methods reported were not mutually exclusive, with the majority of survey respondents using more than one water source and irrigation method. The respondents were also asked to estimate their water use, yet we found that most respondents had very little idea of how much water they actually used in their food garden areas. Owing to the large diversity of water sources (five in total) and irrigation methods (six in total), we concluded that 'estimated water use' was too complex a term to accurately provide a quantifiable result via survey. Future work collecting in-field water use data would be more accurate and beneficial.

A broad range of estimated setup costs were reported by the survey respondents with high variability (Figure 5). This variability was partially due to the differing levels of detail in the responses. Some respondents included only the cost of seeds or seedlings, others added the cost of soil, fertilizer, and building supplies, and some went to great levels of detail, documenting not only the building of garden beds/wicking beds/orchards, but also the purchase and installation costs of new rainwater tanks, irrigation systems, or grey water recycling systems. The setup costs therefore ranged from $0 to AUS$20,000, and the median amount spent was AUS$500. There was a moderate positive correlation between the area under production and garden setup costs (Spearman correlation: $r_s = 0.432$, $n = 304$, $p = 0.001$).

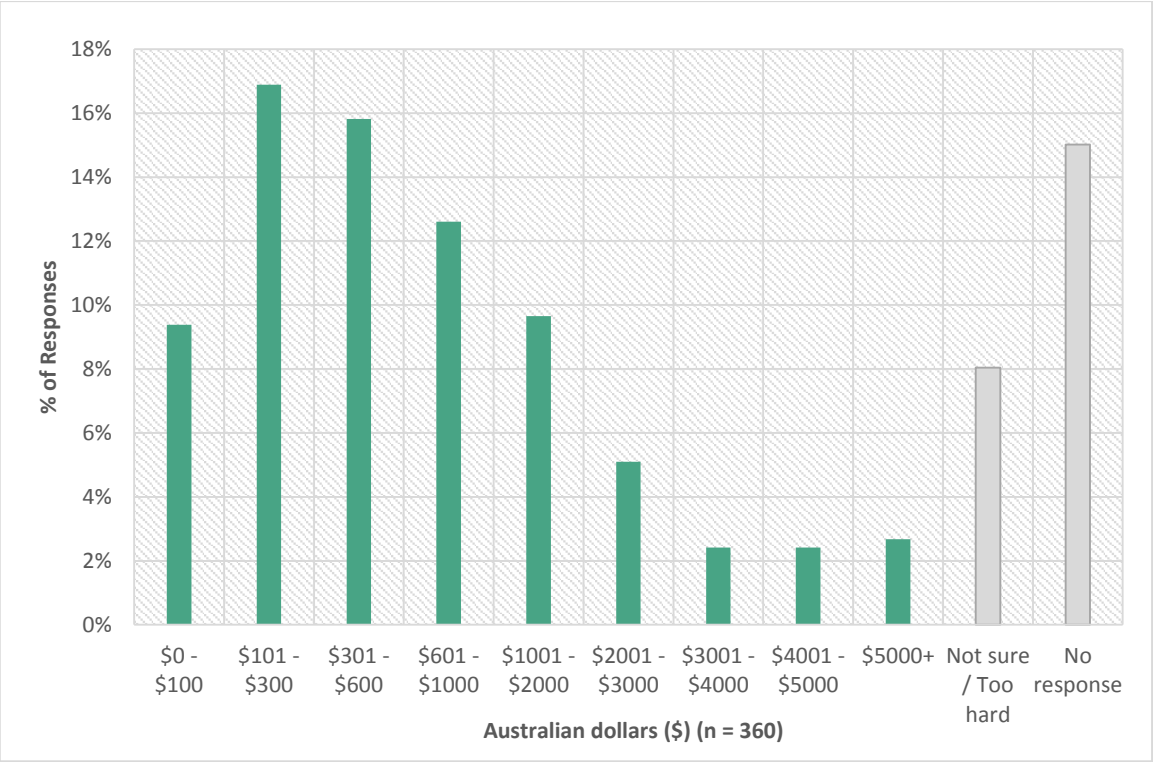

Figure 5. Estimated setup costs of food producing areas. Some respondents found it difficult to estimate their setup costs, hence the "not sure" and "too hard" responses.

When asked to estimate their monthly garden expenses, again there was a broad range of responses from $0 to AUS$1000 per month, with a drop off after AUS$50. The median amount spent was AUS$30 per month. There was a correlation between the total area under production and the monthly costs ($r_s = 0.379$, $p = 0.001$, $n = 325$).

Analysis confirms that there was a significant difference between several other parameters for gardens costing AUS$50 or less per month versus gardens costing more than AUS$50 per month. Gardens costing more than AUS$50 per month had higher setup costs, were larger, had a greater number of food producing areas and production methods in use, and took more time to tend. Gardens that cost more than AUS$50 had higher mean ranks for the areas under production ($U = 8143.5$, $n1 = 279$, $n2 = 46$, $p = 0.003$), a greater total number of production methods ($U = 8143.5$, $n1 = 279$, $n2 = 46$, $p = 0.002$), a greater total number of food producing areas ($U = 8338$, $n1 = 279$, $n2 = 46$, $p = 0.001$), a greater number of weekly hours spent gardening ($U = 8398.5$, $n1 = 272$, $n2 = 46$, $p = 0.001$), and a higher total setup cost (no outliers) ($U = 6534.5$, $n1 = 254$, $n2 = 35$, $p = 0.001$).

There were also some significant differences between gardeners who spent less than AUS$10 per month and those who spent more than AUS$10 per month. While the majority of both groups agreed that they grew food to save money, those who spent less than AUS$10 per month were more certain that they succeeded in saving some portion of their household fruit and vegetable budget (Mann–Whitney U test: U = 5243, $n1 = 58$, $n2 = 219$, $p = 0.038$, difference (≤10–>10) = 1.00 (CI 95% 0.00 to 1.00)).

Building on the initial cost questions, the survey respondents were asked whether they thought they succeeded in saving money in their weekly household fruit and vegetable budget and if so, to what extent (Table 3). In all, 47% believed that they did save some amount of their fruit and vegetable budget, 13% were unsure, 13% thought they broke even, 14% didn't think they saved any money, and 6% were adamant that they did not save any money. There was also a moderate positive correlation between respondents wanting to save money and thinking that they succeeded in doing so (Spearman correlation: $r_s = 0.515$, $n = 297$, $p = 0.001$).

Table 3. Home food gardener responses to the question "Do you save some portion of your household fruit and vegetable budget by growing some of your own food?".

Available Responses	Responses (n = 358)
Unsure	**14%**
No, I know I don't save money	**6%**
No, I don't think I save money	**14%**
I think we break even	**12%**
Yes, 0–5% of my weekly household produce budget	**13%**
Yes, 6–25% of my weekly household produce budget	**15%**
Yes, 26–75% of my weekly household produce budget	**16%**
Yes, over 75% of my weekly household produce budget	**4%**

3.6 Theoretical Comparison Results

Ward et al. (2017) sought to maximize the net value of hypothetical urban food gardens according to the area under production, by considering the nutritional value and water efficiency of crops in different climates. Two-stage linear programming was used to select an optimal mix of crops according to their water use and dietary value. Constraints were applied to ensure that the model selected a combination of crops

from a range of dietary food groups—thus better mimicking the mixed-crops common to home food gardens. This approach was intended to produce a more realistic garden model rather than to optimize purely by yield or crop retail value, which tends to select only single high-yielding, high-value crops (a "cash crop") that would be unrealistic at the household garden scale. Ward et al. (2017) contributed the idea that the size of a garden and how it is watered are important to the economic sustainability of urban food gardens, but their model did not allow for the consideration of the related expenses or the labour invested.

The EG survey results, which are applicable to the Ward et al. (2017) optimization model include the number of people in the household, their years of gardening experience, the size of the area under production, and the types and number of production methods used. Ward et al. (2017) calculated optimized crop mixtures for different climates and various sized areas under production as m^2 per person. The majority (70%) of the EG survey respondents had less than 15 m^2 (category 1: tiny (<4 m^2/person) (21%) and 2: small (5–15 m^2/person) (49%)) of area under production per person in their household (see Supplementary Table S1). According to the optimization model, these gardens would ideally be growing a limited range of crops suitable for Adelaide's climate, namely: broad beans, basil, zucchini, strawberries, tomatoes, and eggs. While the EG survey did not specifically ask respondents which crops they grew, it did ask which production methods they utilized from a list of 11 possible methods (for example, raised gardens beds, fruit trees, keeping chickens, etc.) Without specific crop data, it was difficult to calculate whether or not the EG respondents were following anything akin to the optimized mix recommended by Ward et al. (2017). However, according to their areas under production, the EG respondents were theoretically well-placed to achieve the best possible returns for water applied per unit area and net value.

Keeping chickens for egg production is an interesting production method, with 39% of the EG survey respondents listing 'Poultry—Chickens', 5% of respondents listing 'Poultry—Other', and some respondents listing both chickens and other poultry. In the

optimization model, chicken eggs were consistently selected for all area categories as being both a high-value and water-efficient crop for urban food gardens.

Fruit trees are one of the main points of difference between the optimization model and the EG survey data. Fruit trees were present in 84% of the EG respondents' gardens, making them the most common production method. In contrast, although a range of fruit trees were available in the optimized model, none were selected for their crop value or water-use efficiency in gardens smaller than 80 m^2/person. At 80 m^2/person, orange trees were selected for all climates, and once the model reached 160 m^2/person, almond trees were also selected but only for Hobart's climate.

4. Discussion

4. 1 South Australian Home Food Gardens

Due to past observations in the previous literature regarding variable yield rates and different growing approaches in urban agriculture generally, it was anticipated that there would be a reasonable level of diversity among the EG survey respondents' food gardens. Once analysed, the EG survey results revealed the full extent of home food garden diversity. Figure 6 is a graphical depiction of a statistically typical urban food garden based on median survey results from the EG project.

We found a great diversity of garden setups, garden inputs, and gardeners themselves. This diversity confirmed the results of Wise (2014), who found it difficult to describe the "typical" Australian home or community gardener, the survey results showed that the EG respondents ranged in age from 18 to over 81 years. One-third of the respondents had young children (primary school age or younger) and one-sixth had someone over the age of 65 present in the household. There was, however, a prevalence of respondents who were female (77%), home owners (85%), and highly educated (66% holding a bachelor's degree or higher). The combination of the high number of home owners, high education levels, and the disproportionately high IRSAD rankings indicates that the majority of the EG survey respondents are in a position of relative socio-economic advantage.

Much of the difficulty of studying urban food gardens lies in the sheer diversity of garden setups. When every food garden is different, how can they be accurately measured or compared? Two of the underlying differences among food gardens include gardening approaches (Figure 3) and production methods (Figure 4). Past UA yield studies have tended to focus more on where the food gardens were located and what crops were being produced, while only occasionally referencing the production methods used (Codyre et al. 2014; Gittleman et al. 2012; Kortright et al. 2011; Pourias et al. 2015; Vitiello et al. 2010; Vitiello et al. 2009; Wise 2014). Zainuddin et al. (2014) were one of the few to notice the extensive range of practices used in their study of home food gardens. They found that most of their participants made use of more than one practice, thus making categorization challenging. Each of these practices (which we have separated into "gardening approaches" and "production methods") have individual advantages and disadvantages, which could in turn impact the resource efficiency and productivity of each food garden. Figure 6 shows that the EG survey respondents typically make use of a combination of four different gardening approaches and four different production methods. It was anticipated that the most dominant gardening consistency would be seasonal, with people growing food during spring/summer but then letting the garden lie fallow over autumn/winter. However, this was not the case with the majority of the EG respondents (62%) growing 'all through the year'. Upon reflection, with such a large proportion (42%) of the EG respondents reporting having 11+ years of gardening experience, the categories could have been extended further. Yet this question was initially designed to identify less experienced respondents, rather than to measure the full range of experience.



Total area under production: small 5-15m2 (28%) OR medium 16-30m2 (28%).
Gardening consistency: "All year round" 62%

Typical no. of production methods: 4

Top 5 production methods: 1. Fruit trees (84%), 2. Pots & planters (74%), 3. In-ground beds (70%), 4. Raised beds (61%), 5. Poultry– chickens (39%)

Typical no. of gardening approaches: 4

Top 5 gardening approaches: 1. Composting (70%), 2. Conventional digging & tilling (66%), 3. Organic (57%), 4. Companion planting (53%), 5. Low use of chemical pesticides & pesticides (48%)

Typical no. of water sources: 2

Top 2 water sources: 1. Mains water (82%), 2. Rainwater (60%)

Typical no. of irrigation methods: 3

Top 3 irrigation methods: 1. Manual (86%), 2. Drip irrigation (51%), 3. Sprinkler (25%)

Typical time spent: 4 hours per week (range = <1—30 hours)

Typical setup cost: $500 (range: $0—$20,000); **Typical monthly cost**: $30 (range = $0—$1,000)

Do you produce food to save money? 47% 'Agree'
Do you think you succeed in saving money? 48% 'Yes, some money'

Top 6 original challenges: 1. Lack of time; 2. Unsuitable space, soil, climate; 3. Not enough space; 4. Lack of knowledge; 5. Livestock, pet or pest issue; 6. Cost

Do you experience any current challenges? 38% = 'No', 62% = 'Yes'

Top 6 current challenges: 1. Lack of time; 2. Unsuitable space, soil or climate; 3. Livestock, pet or pest issue; 4. Water issues; 5. Physical / health issues; 6. Cost

Figure 6. A sketch of the "typical" home food garden based on the median survey results from the Edible Gardens online survey (*n* = 379). The coloured markers in the image relate to the colours in the reference table and represent the different aspects of the "typical" garden.

4.2 Differences between the 'Optimized Garden Model' and the EG Survey Data

When comparing the EG survey data with the optimized garden model by Ward et al. (2017) some key differences were found. These differences included the prominence of fruit trees, the value of time, and the likelihood of yield variability. The very high prevalence of fruit trees in small South Australian home food gardens—when they were not selected at all by the optimization model due to low yield and high water demand—has several plausible explanations. It is possible that fruit trees, once established, are a particularly resilient type of food production, which can produce reasonable yields even when little time and effort is devoted to them. Had the optimization model included labour inputs and constraints, perhaps fruit trees would have emerged in preference to higher-yielding (but more labour-intensive) vegetables. Historically, small orchards were a common feature of the typical "quarter-acre block" dominating South Australian suburbs until relatively recently (Auricht 2010; Gaynor 2006). It is possible that many of the established fruit trees being tended by the EG respondents are left over from larger gardens even as house blocks are sub-divided into smaller areas (Auricht 2010). Moreover, in the last five years, the price of mains water in South Australia has risen dramatically (Australian Bureau of Statistics (ABS) 2016a; Ward et al. 2017), so there are likely to be trees planted perhaps as recently as 10 years ago that may have made greater economic sense then, but are now costing more to irrigate. Future research could explore the relative costs and benefits of replacing established fruit trees with new vegetable gardens; it may be that the greatest cost-benefit ratio comes from maintaining fruit trees that are already established.

Due to the lack of in-field UA data available on various crop yields, Ward et al. (2017) had no option but to base their optimized garden yields on consistent commercial yield rates. As home food gardens do not need to account for commercial machinery access, they can pack more plants into a smaller area—thus potentially achieving higher yields per square meter (Fortier 2014). This seems particularly relevant for urban fruit trees, which can share at least some of their space with other garden uses (both productive and recreational). However, such advantages remain largely unquantified, with high

yield variability noted by many UA studies (Algert et al. 2014; Codyre et al. 2014; Conk 2015; Vitiello et al. 2010; Vitiello et al. 2009; Zainuddin et al. 2014).

Gardener experience may also influence the productivity of a food garden. Codyre et al. (2014) observed a general relationship between the length of time gardening and the efficiency of their gardeners (efficiency was calculated as high production rates and lower input costs of their food producing areas). This aspect of gardener experience is worth investigating further in future UA research. Understanding gardener experience may even offer an additional explanation for the popularity of fruit trees over vegetables, as it is plausible that trees are viewed by less experienced gardeners as being more forgiving of mistakes.

Applying a value to time invested can be complex. Ward et al. (2017) assumed time spent to be discretionary, thus their model cannot make recommendations on crop types suitable for those with less time. With 'lack of time' listed as both the top initial and top current challenge, it would be worthwhile to attempt to incorporate time in any future garden models. Even without applying a wage rate to the time spent, time-poor urban gardeners would benefit from guidance on which crops or production methods provide the greatest return on time invested.

In summary, it appears that real-world home food gardens differ from "model" food gardens chiefly through their inclusion of fruit trees as a widespread production method. Further work is necessary, especially the incorporation of better yield data and time, capital, and ongoing costs into the model. All of these parameters are likely to have a significant influence on the model of an optimal food garden.

4.3 Challenges to Home Food Gardening

The EG survey asked about initial and current challenges to the respondents' food production. While all respondents answered the initial challenges question, only 61% reported having any current challenges. Both the top initial and top current challenge was lack of time. The idea of people not having enough time, or the perception that growing food requires a considerable amount of time, is commonly documented in past UA studies (Conway 2016; Newman 2008; Wise 2014; Zahina-Ramos 2013). The

EG survey respondents also estimated the amount of time they spent on their food gardens per week. Weekly time spent ranged from less than one hour to more than 20 hours, with a median of four hours. While four hours may sound like a lot, when distributed over an entire week this is approximately 30 minutes per day. The amount of time spent estimated by the EG respondents was considerably higher than that reported by Wise (2014). Wise (2014) asked respondents to estimate the time they spent in the last month on their food gardens. Wise's (2014) results suggested that 19% of people spent less than 15 min per week, 60% spent between 15 min and 2.4 h per week, and 22% spent more than 2.6 h per week. While the EG survey data gives an estimation of how much time our respondents think they spent on their food gardens, more work is required to gather in-field garden data on the actual time spent. There may be differences in time spent among various gardening activities, production methods, gardening approaches, crops, or irrigation methods. One example of this is Cleveland et al. (1985), who found that they spent approximately 50% of their time watering by hand. They were one of the few to record labour data by activity. Labour data collected on different food gardens and activities would provide some insight into which methods are best suited to those who lack time.

The challenge category of 'unsuitable conditions' related to unsuitable space, soil, and general garden conditions, such as "not enough sun" or "too hot in the summer". 'Unsuitable conditions' held its place at number two in both lists of initial and current challenges. This challenge appears differently in past UA research: Wise (2014) reported the top barrier as '[n]ot enough/unsuitable space'; Conway (2016) reported both 'shading' and 'lack of space' as top barriers; and 'lack of space' was reported by Zahina-Ramos (2013). It is also possible that in previous UA research, perceptions of 'lack of space' were indistinguishable from 'unsuitable conditions', particularly for gardeners with little experience. Inexperienced gardeners may not realize how many food plants can be packed into small spaces, nor be aware of space-saving growing techniques, such as growing food in vertical gardens, in window boxes, or even on their street verge.

There was an interesting transition in the top challenges from initial to current (Table 2). 'Lack of knowledge' and 'cost' were replaced on the list by 'water issues' and 'physical/health issues'. It is possible that as knowledge and experience with food production increases, the health and physical capability required to accomplish the more strenuous gardening tasks can decrease. The level of people's gardening experience has been suggested in past research to be correlated to their overall productivity (Algert et al. 2014; Codyre et al. 2014). Conway et al. (2014) conducted a study in Canada on home food gardens as a landscaping choice and found that one-third of their study participants had only begun edible food gardening within the last five years. Conway et al. (2014) and Wise (2014) discuss the high turnover of those taking up and then abandoning their food gardens. People with less gardening knowledge and experience are more likely to encounter failure early on, and this disappointment can lead them to give up on their food gardens (Wise 2014).

Water in urban food gardens is often overlooked. Not only is water a vital input for gardens, but in many places around the world fresh water is becoming scarcer and more expensive. The water use of UA remains challenging to measure, and indeed, only one study—three decades ago—has reported both water use and water cost (Cleveland et al. 1985). The EG survey respondents typically made use of two water sources and three irrigation methods (Figure 6). Water issues appeared at number six on the list of top initial challenges and number four on that of current challenges. By comparison, water was not mentioned as a challenge or barrier by several previous UA studies (Conway 2016; Kortright et al. 2011; Newman 2008; Wise 2014; Zahina-Ramos 2013). This difference may partly be due to the greater water awareness of South Australians as residents of the driest state in Australia (Australian Bureau of Statistics (ABS) 2015).

Livestock, pet, pest, or wildlife issues remained as both an initial and a current challenge for gardeners. The majority of the comments related either to an animal or pest coming into the food garden and eating the produce or simply causing damage to the garden. This particular challenge did not appear in the Australian survey by Wise (2014), but "attracting animals/insects" was a top barrier in the Canadian study by

Conway (2016), and insect pests were briefly mentioned in the American study by Zahina-Ramos (2013). Coupled with our respondents' high affinity for organic and low-chemical gardening approaches, appropriate pest management appears to be an area worthy of further research. In general, a better understanding of that which can hinder or prevent people from growing food, or even cause them to cease growing food altogether, may assist in designing the right kind of support.

4.4 Implications for Economic Sustainability of Home Food Gardens

There remains considerable discussion around the potential capacity for UA to support urban food security and reduce the cost of living for households (Butterfield 2009; Fortier 2014; Langellotto 2014; Ward et al. 2014a; Wise 2014). A survey by Butterfield (2009) reported that 54% of American households were growing food in order to save money on their food bills. In Australia, 91% of the home and community gardeners in Wise's (2014) study slightly or strongly agreed that they save money by growing some of their own food. Wise (2014) did however conclude that there is not enough evidence to support the argument that growing food in urban areas saves households money. Indeed, Conway (2016) found that only one of his participants identified saving money as a motivation, while 16% actually reported the cost of growing food as a barrier. In order for UA to flourish and be sustained, careful attention should be paid to whether the activity can, or should, be expected to save households money.

The EG survey respondents' high education levels, high percentage of home ownership, and high relative IRSAD rankings indicate that the majority of the EG respondents were not the households that would most benefit from financial savings. This is not to say that our survey respondents did not wish to save money; indeed, 42% 'agreed' and 17% 'strongly agreed' that they grew food to try to save money. When asked whether they believed that they succeeded in doing so, 48% believed that they saved some portion of their household fruit and vegetable budget.

While 'cost' was one of the top initial challenges for people, it did slip slightly down the list of top current challenges to lower than 'lack of space'. The fact that cost was an initial challenge for our survey respondents suggests that it would also be the case, if not more so, for lower-income households. Initial outlay (and ongoing expenses) are

important factors when trying to assess the financial feasibility of home food gardens. Measurement of production costs has only been selectively included in past studies (Algert et al. 2014; Codyre et al. 2014; Conk 2015; Gittleman et al. 2012; Pourias et al. 2015; Vitiello et al. 2009; Ward et al. 2017; Zainuddin et al. 2014). The initial outlay required to set up a food garden may present a serious fiscal challenge, particularly for households with little disposable income. Of course, not all of the EG survey respondents spent large sums of money setting up their gardens, with 9% spending less than AUS$100. Indeed, the median setup amount was AUS$500 and the full range was AUS$0–AUS$20,000. The monthly amounts people reported spending on their gardens ranged from AUS$0 to AUS$1000, with a median amount of AUS$30.

Separate from the strict weighing of costs versus net savings, is the older concept of 'thrift'. Thrift is defined as "the quality of using money and other resources carefully and not wastefully". Being thrifty by growing some of your own food has strong ties to living a less wasteful and more ecological lifestyle (Gaynor 2006). Indeed, as use of the word 'thrift' diminished around the 1950s, it did not take long for a new word—'sustainability'—to rise in its place (Yates 2012). Some home food gardeners may view their time and money as worthwhile resources to spend in exchange for engaging in other sustainable behaviours, such as composting their food and garden wastes or caring for the environment by growing food organically. Of course, there are also the well-documented social, mental, health, and education benefits associated with engaging in and practicing UA (Alaimo et al. 2008; Block et al. 2012; Kingsley et al. 2006; Soga et al. 2017; Wood et al. 2016; Zick et al. 2013).

At this point in time, based on the survey results, it remains unclear whether producing food in urban areas is fully accessible to lower-income households. Yet there is an opportunity to study which food garden setups (production methods, crops, gardening approaches, water sources, irrigation methods, etc.), best lend themselves to low-cost methods to assist in increasing the financial accessibility and economic sustainability of home food gardens.

5. Recommendations for Future Work

The authors strongly recommend further research into the sustainability of UA, particularly via in-field data collection on a range of home food gardens. There should also be a focus on collecting consistent, year-round input data, including time spent, water-use, and expenses for a variety of different production methods and crop types. Gardener experience is another variable worth taking into account. In order to respect the diverse variety of existing UA, it is important that these data be collected on existing urban food gardens as they are currently designed and managed. Doing so will provide realistic data on the resource efficiency, productivity, and requirements of food gardens in modern urban areas.

6. Conclusions

Urban agriculture is an incredibly diverse and variable field of study. Past research into home food gardens observed a variety of crops, yield rates, growing periods, gardening approaches, and garden placements. The Edible Gardens project has revealed further variety in production methods, water sources, irrigation methods, sizes, labour, and costs of urban home food gardens in South Australia. Each of the three facets of sustainability—social, economic, and environmental—are likely to be influenced in different ways by the diversity of UA. With regard to the financial accessibility and economic sustainability of home food gardens, there is still much more work to be done. Although saving money was a top motivator for the EG respondents, with many believing that they succeeded in saving money, it remains to be seen whether their current gardening practices support this desire. Measurement of the full costs of different gardens would allow better predictions of whether growing food can save households money and under what circumstances. Lack of time, in particular, continues to be a challenge for urban food gardeners. The differences between the optimized garden model by Ward et al. (2017) and the EG survey data further highlight the gap in knowledge regarding existing home food gardens. In particular, a high prevalence of fruit trees was reported by the EG respondents, in contrast to the complete lack of fruit trees in Ward and Symons's optimized garden design (where the model deemed trees to have low yield and high water use). These

discrepancies may relate to nuances around different levels of gardener experience, established trees already existing in gardens, and the suitability of trees for time-poor gardeners. All of the findings in this study indicate that UA is a field that is ripe for further research.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1: Figure S1: Total area under production reported by the EG survey respondents, Figure S2: Estimated average time spent per week by the EG respondents on their food gardens, Table S1: Comparison of the EG area under production categories with the square meter per person categories from Ward and Symons's (2017) optimized garden model, and the full list of reported survey questions.

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5 Beyond Productivity: Health, Wellbeing & Social Value



Overview

Beyond the physical productivity and resource efficiency of urban agriculture (UA), there are myriad other ways in which people benefit from growing some of their own food. Chief among these are the potential benefits for health and wellbeing, social value and simple happiness. The argument exists that these benefits are valuable in their own right, regardless of the productive "success" of people's urban food gardens.

There currently exists widespread concern over people's health and wellbeing, particularly those living in urban areas. Amid the different nature-based opportunities which exist for supporting good health and wellbeing is gardening, and by extension, growing food. It remains unclear, however, whether the mental health benefits documented in other forms of UA (where the research is dominated by community gardens) are also present in home food gardens (the most common form of urban agriculture in Australia).

The aim of the research presented in this chapter was to investigate the perceived health, social value and happiness benefits of UA by focussing on home and community food gardens in South Australia. Building on the previous work presented in Chapter 4, this paper presents results from two parts of the Edible Gardens Project: 1) the remainder of the results from the online survey – from questions relating to the motivations, social value and social capital of UA, food preservation and food distribution; and 2) results from the in-field garden data collection – specifically the tracking of home grown produce shared with others.

It was important for this research to include not just the growing of food, but to also consider the full cycle of what happens once the food is harvested. It can be eaten fresh by the household, preserved, processed or stored in some way, or distributed to others outside of that household. Food preservation can be both a practical way to extend the life of a harvest and an emotional process (Click et al. 2010; Deppe 2010; Pollard et al. 2017). Historically, there were times when civilisations and communities depended not only on their ability to grow food during the year, but also on their ability and capacity to store parts of their harvests for the "lean times". The knowledge, skills and capacity to preserve food, in addition to the distribution and sharing of excess food with others, can be a valuable contributor to urban food security and overall resilience.

This chapter allows for an in-depth exploration of the non-productive side of UA. Key differences between the home and community gardeners involved are identified and the multi-faceted role of these two forms of UA to act as supporting or preventative mechanisms for resilient health and wellbeing are critically evaluated.

This chapter contributes to research objectives:

2. *Develop and implement a novel approach to enable widespread measurement of urban agriculture input and yield data on existing urban food gardens.*

3. *Clean, manage and analyse collected data from both Phase 1 and 2 to gain an in-depth understanding of current urban food gardens in South Australia.*

4. *Respect and acknowledge the reciprocal relationship with the 'citizen scientists' (survey respondents and selected phase 2 participants) who contributed data to the Edible Gardens project.*

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Preparation by G.P.; Writing-Review & Editing by G.P., J.W., P.R., E.M. and B.C.; Supervision by J.W. and P.R.; Funding Acquisition by P.R.

The format of this paper has been altered for consistency with the rest of the thesis.

Paper 4: Beyond productivity: Considering the health, social value and happiness of urban food gardeners

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Abstract

We are living in an age of concern for mental health and wellbeing. The objective of the research presented in this paper is to investigate the perceived health, social value and happiness benefits of urban agriculture (UA) by focusing on home and community food gardens in South Australia. The results reported in this paper are from "Edible Gardens", a citizen science project designed to investigate the social value, productivity and resource efficiency of UA in South Australia. Methods include an online survey and in-field garden data collection. Key findings include: dominant home gardener motivations were the produce, enjoyment, and health, while dominant community gardener motivations were enjoyment, connection to others and the produce. Exploratory factor analysis revealed four key factors: Tranquillity and Timeout, Develop and Learn Skills, the Produce, and Social Connection. The key difference between home and community gardeners was an overall social connection. Although home gardeners did not appear to actively value or desire inter-household social connection, this does not mean they do not value or participate in other avenues of social connection, such as via social learning sources or by sharing food with others. The combined results from this research regarding health and wellbeing, social connection and happiness support the premise that engagement in home or community food gardening may provide a preventative or supportive role for gardener health and wellbeing, regardless of whether it is a conscious motivation for participation.

Keywords: urban agriculture; urban food production; health; mental health; wellbeing; South Australia; social capital; social value; home gardens; community gardens

1. Introduction

We are living in an age of concern over the mental health and wellbeing of people, including the growing population in modern urban areas. According to the World Health Organization, depression is now the leading cause of ill health and disability worldwide with more than 300 million people affected (World Health Organization 2017). In Australia, each year, almost 1 in 5 Australians will experience a mental illness such as anxiety or depression, while 45% of Australians will experience a mental illness at some point during their lifetime (Australian Bureau of Statistics (ABS) 2008). The majority (69%) of Australians now live in urban areas (Australian Bureau of Statistics (ABS) 2013). There is a growing realisation that connection to nature, which may be diminished in urban settings, makes important contributions to our mental health and wellbeing (Capaldi et al. 2015; Korpela et al. 2014; MacKerron et al. 2013; Soga et al. 2016; Uhlmann et al. 2018). Social isolation, such as lacking regular social contact or support from friends or family, is another contributor to poor mental health (Australian Bureau of Statistics (ABS) 2009). Experiencing nature has been found to have prosocial effects by increasing feelings of generosity, kindness, and empathy towards others (Capaldi et al. 2015) by reducing personal feelings of anxiety (Martyn et al. 2016), and because spending time outdoors in natural environments has a positive association with happiness (MacKerron et al. 2013; Zelenski et al. 2014).

Mental health is not just a societal concern but also a monetary one. Mental illness in Australia costs $20–28 billion per year (2009–2013) (Australian Bureau of Statistics (ABS) 2009; Medibank Private Health Insurance et al. 2013). With the growing realisation of the impact of mental health on wellbeing, the South Australia government recently released the South Australian Mental Health Strategic Plan 2017–2022 (Government of South Australia 2017). The Department for Health and Wellbeing has also partnered with the Department for Environment and Water to create the "Healthy Parks, Healthy People Initiative" (Government of South Australia 2016) to encourage all South Australians to engage more with nature. This initiative has

resulted in a promotional campaign called "Five Ways to Wellbeing with Nature", which urges people to practice five simple actions: Connect, Be Active, Keep Learning, Take Notice and Give. Each of these five actions can be practised not just in large natural spaces such as national parks or wilderness areas, but are also applicable to smaller urban green spaces such as parks or gardens (Government of South Australia 2016).

Amid the different nature-based opportunities for supporting good mental health and wellbeing is gardening (Buck 2016; Clatworthy et al. 2013; Freeman et al. 2012), and by extension, growing food (Uhlmann et al. 2018). Producing food and keeping urban livestock in and around the fringes of urban centres is known as urban agriculture (UA). There are many different forms of UA including home gardens, community gardens, allotments, school gardens, community orchards, land-sharing, and other UA businesses. Prior research has shown engagement in UA to improve mental health and wellbeing (Maheshwari 2017; Soga et al. 2017; Wood et al. 2016) by lessening feelings of depression and fatigue (Wood et al. 2016), supporting stress management (Maheshwari 2017), and encouraging social cohesion (Soga et al. 2017). However, little research has focussed purely on the potential for home food gardens, the most common form of UA in Australia (Wise 2014) to support mental health, wellbeing, and social capital. In part, this may be because of the difficulty of conducting research on home food gardens due to their sheer diversity, geographic spread and low physical accessibility and visibility (Conway 2016; Kortright et al. 2011; Taylor et al. 2013). It remains unclear whether the mental health benefits documented in other forms of UA (such as community gardens) are also present in home food gardens. There are of course many other forms of UA occurring in and around the fringes of urban centres, however, this study focusses purely on home and community food gardens. Recommendations for further research into food gardeners' motivations, barriers to participation (particularly for new gardeners), and what they perceive as the value of UA, have been strongly advocated by Nugent (2000), Petts (2005) and Wise (2014).

The aim of this paper is to investigate the perceived health, social value and happiness benefits of the UA, in particular, focusing on whether home gardeners obtain similar

benefits as community food gardeners. South Australia is presented as an interesting case study due to its recent adoption of several mental health and wellbeing initiatives (Government of South Australia 2016, 2017), and the high level of participation in urban food production in the state (59% of the population) (Deppe 2010). Previous work by Pollard et al. (2018) examined the diverse nature of UA in South Australia by reporting survey results on the physical, practical and economic aspects of home food gardens, stemming from a research project called "Edible Gardens". Building on that work, this paper includes results from two sources, both part of the Edible Gardens project: 1) responses to survey questions relating to the motivations, social value and social capital of UA, food preservation, and food distribution, and 2) results from in-field garden data collection tracking home-grown produce shared with others. The discussion focusses on the deeper motivations, meaning and value behind growing food, in addition to the many different avenues of social connection. Previous studies have shown that growing food at home may not be cost-effective on a purely economic basis, particularly when applying a wage-rate to invested labour (Cleveland et al. 1985; Codyre et al. 2014; Pollard et al. 2017; Stall 1979; Utzinger et al. 1978). The results of this paper are therefore of significance in the context of valuing the contribution made by home food gardens beyond productivity.

2. Materials and Methods

"Edible Gardens" (EG) was a citizen science project designed to investigate the social value, productivity and resource efficiency of UA in South Australia. It was launched in late 2016 by the Discovery Circle—a citizen science initiative of the University of South Australia. The project received approval from the Human Research Ethics Committee of the University of South Australia in January 2016 (Protocol number 0000034940). Phase 1 of the Edible Gardens project was an online 'Survey Monkey' survey designed to ask food gardeners across South Australia about their motivations, values, challenges, learning sources, food preservation methods, food sharing and many other practical aspects of their food gardens. The survey included closed, open, category and ranking questions (for the full list of related survey questions please refer to the Supplementary Table S1). The project was promoted on the Discovery Circle website and Facebook page, and via other print materials and press releases from the

project sponsors: The University of South Australia, the Department for Environment and Water, the Adelaide and Mount Lofty Ranges Natural Resources Management Board, the City of Salisbury and the City of Marion. From September 2016 to May 2018, 402 respondents completed the online survey. Each of the reported samples sizes presented in the results was determined by the number of responses to each survey question. Incomplete, skipped or non-applicable responses to particular questions were removed during data cleaning.

Part of the online survey was based on the Recreation Experience Preference (REP) Scale, originally developed by Driver (Driver 1983) to measure experience preferences for national parks and wilderness areas. In Australia, the original REP scale was adapted by Weber et al. (2010) to study the experience preferences of more urban parks and green areas. A REP-based scale of 30 individual Likert-style scale statements, focused on food production was used in the Edible Gardens survey (for the full list of REP scale statements used in this study, please refer to the Supplementary Table S2). Open-answer questions on what respondents valued about growing food were also included in the online survey, to provide a contrast to the modified REP scale.

The survey also investigated the social capital levels of the respondents. Social capital is defined by Martin et al. (2004) as "a measure of trust, reciprocity and social networks" and thus is suitable for UA research investigating the social connection between food gardeners. The quantitative seven-item Likert scale tool developed and validated by Sampson et al. (1997) to measure social capital levels was used. This tool was used in conjunction with additional questions recommended by Martin et al. (2004), to ascertain any involvement in collective action activities, the presence of elderly household members, and both household and neighbourhood tenure. The median score of each respondent to the social capital questions was calculated before the median scores of home gardeners and community gardeners were grouped. If a respondent had participated in a group gardening activity, an additional point was added to their personal social capital score to create a 'total social capital score'.

Phase 2 of the Edible Gardens project involved data collection in participants' gardens. Of the survey participants, 58% volunteered to collect data on their own food gardens.

A subset of these (n = 70) was selected to register their gardens, and more than half of those participants followed through with collecting and submitting garden data (n = 39). The participants were selected to ensure a broad range of garden setups and gardeners: garden sizes, production methods, costs (both set-up and ongoing costs), estimated time spent gardening, years of gardening experience and ages of the gardeners. For a full description of the project design please refer to Pollard, Roetman, and Ward (Pollard et al. 2017). Of relevance to this paper was the tracking of any portion of the garden harvest that participants shared with someone outside of their own household. Food gardeners also often experience periods of 'gluts' of a crop, where too much to consume is ready to harvest at one time (Deppe 2010; Vitiello et al. 2010; Zainuddin et al. 2014), hence our consideration of food preservation and food distribution activities. Each gift or sharing of produce was weighed using a spring balance or digital scales, and the crop and recipient of the food were recorded (Recipients were categorised as family, friend, community, food swap or 'other'). Data analyses were conducted in a combination of Microsoft Excel 2016, IBM's SPSS Statistics Software V.25 and QSR NVivo Qualitative Analysis Software V.11.

3. Results

The results are divided into 2 sections: (1) the motivations, learning sources, values and social capital of home food gardeners; (2) food preservation practices and food distribution. These results combine both the Phase 1 survey data and the Phase 2 in-field data from the Edible Gardens project and build on previous work by Pollard et al. (2018) who published the survey results relating to the physical, practical and economic aspects of the respondents' food gardens.

3.1. Motivations, Values and Social Capital

Survey respondents were asked in two ways about what motivated them to grow food. Initially, they were asked why they first decided to start growing some of their own food—their original motivations. Then they were asked to list the top three reasons they currently grew food—their ongoing motivations. These two questions allowed us to identify what draws people to grow food, and how these motivations persist or are replaced over time (Tables 1 and 2).

Table 1. The top 10 original and ongoing motivation categories of Edible Gardens home gardeners.

Home Gardeners (n = 369)					
	Original Motivations	**%**		**Ongoing Motivations**	**%**
1	Produce related (mostly taste & freshness)	44%	1	Produce related (mostly taste & freshness)	70%
2	Enjoyment	35%	2	Health (Mostly chemical input concerns and organic food)	47%
3	Health (Mostly chemical input concerns and organic food)	32%	3	Enjoyment	46%
4	Natural connection	21%	4	To save money	27%
5	To save money	18%	5	Natural connection	25%
6	Tradition	15%	6	Convenience	21%
7	Connection to others (mostly family)	14%	7	Satisfaction & accomplishment	21%
8	Satisfaction & accomplishment	14%	8	Environmental consideration	18%
9	Knowledge building	14%	9	Connection to others (mostly family)	17%
10	Convenience	13%	10	Knowledge building	17%
Average length of food growing experience: 11+ years (43%) and then 1-5 years (30%).					

Table 2. The top 10 original and ongoing motivation categories of Edible Gardens community gardeners.

Community Gardeners (n = 20)					
	Original Motivations	**%**		**Ongoing Motivations**	**%**
1	Enjoyment	35%	1	Connection to others (mostly community interaction)	70%
2	Connection to others (community interaction)	30%	2	Produce related (mostly freshness, taste and variety)	47%
3	Produce related (mostly taste and freshness)	25%	3	Enjoyment	46%
4	Health (mostly organic food)	20%	4	Natural connection	27%
5	Environmental consideration (carbon footprint)	15%	5	Satisfaction and accomplishment	25%
6	Natural connection	15%	6	Contribute to self-sufficiency	21%
7	Knowledge building	10%	7	Health (mostly organic food)	21%
8	Satisfaction and accomplishment	10%	8	Knowledge building	18%
9	To save money	10%	9	Environmental consideration	17%
10	Tradition	10%	10	To save money	17%
Average length of food growing experience: 1–5 years (40%), and then 11+ years (35%).					

The top four persistent motivations were related to produce, enjoyment, health (for home gardeners) and connections to others (for community gardeners). There was some shifting of the lesser ranked motivations over time for both sets of gardeners. The

main differences in the motivations of home and community gardeners related to both the ranking and content of the 'Connection to others' motivation. For home gardeners, 'Connection to others' ranked 7th and 9th in the list of motivations and mostly referenced family and time with children. For community gardeners, 'Connection to others' ranked 2nd and 1st on their lists of motivations and mostly referenced community interaction. The motivation 'To save money' was ranked higher by home gardeners (5th and 4th) than by the community gardeners (9th and 10th). Other differences include 'Convenience' which ranked 10th and 6th for home gardeners but did not appear in the top ten for community gardeners, and the 'Health' motivation contained differently coded content, with home gardeners mostly referencing chemical or input concerns and organic food, while the community gardeners mostly referenced just organic food. While 'Health' did shift down the list of ongoing motivations, it did retain a similar percentage over time.

Respondents were also asked from where, or from whom they learned about food gardening (Figure 1). The more inherently social learning sources appear in the lower half of Figure 1. Most respondents (57%) learned from two or three social learning sources and three less-social sources (51%). Greater numbers of social learning sources positively correlated with greater numbers of production methods (Spearman correlation: $r_s = 0.246$), gardening approaches (Spearman correlation: $r_s = 0.326$) and irrigation methods (Spearman correlation: $r_s = 0.204$), in addition to higher gardening consistency (Spearman correlation: $r_s = 0.219$) and giving food to more groups of people (Spearman correlation: $r_s = 0.235$). A Spearman correlation is a non-parametric test for assessing the relationship between two samples (Hawkins 2014). Both the terms 'production methods' and 'gardening approaches' have been defined and described in a previous paper (Pollard et al. 2018). 'Production methods' relate to the different physical methods to grow food, for example, in-ground beds or raised beds, while 'gardening approaches' relate to the grouping of the more theoretical approaches to growing food, for example, organic, permaculture or companion planting.

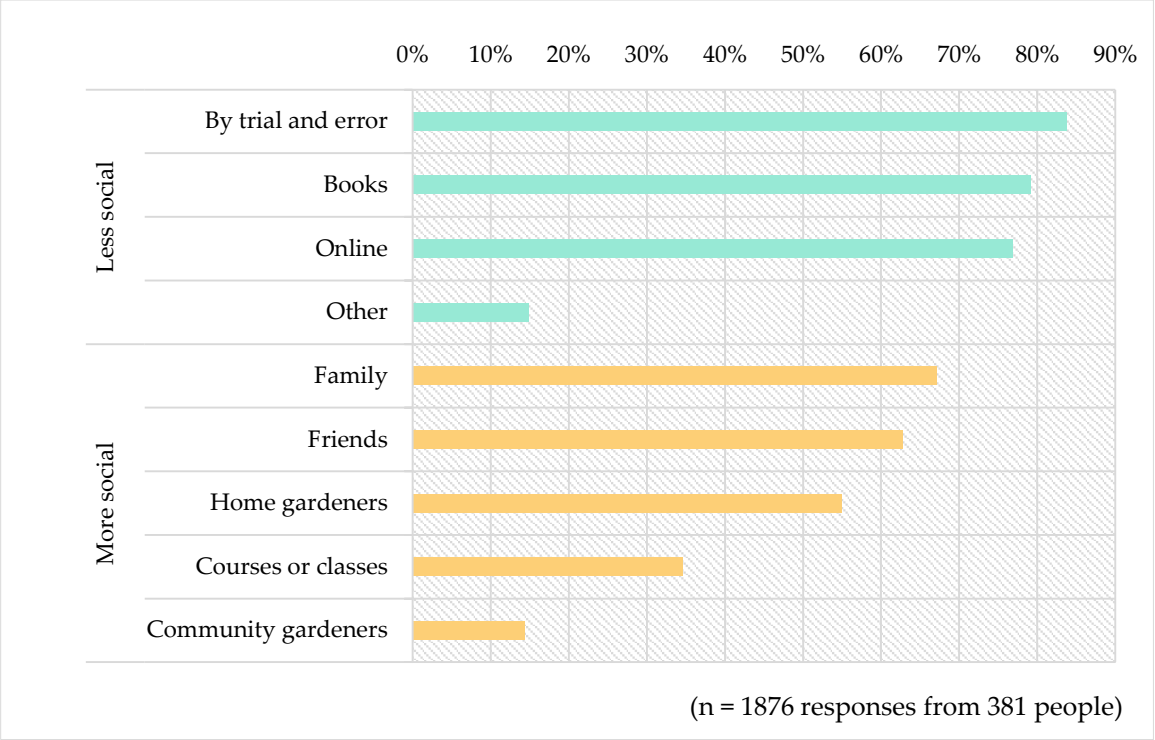

Figure 1. The responses to the question, "from where have you learned about food gardening?" The 'other' category mostly refers to sources such as TV shows, magazines or radio. Please note the responses were not mutually exclusive.

3.1.1. Values

Exploratory Factor Analysis using Principal Axis Factoring with Varimax Rotation and Kaiser Normalisation was applied to 27 of the 30 REP scale statements (n = 372) (Table 3). Three of the statements were removed from the list of REP scale items as they did not load strongly onto any factors. These statements were, "I produce food to spend time with my family", "I produce food to spend time without my family" and "I produce food to save money". Ten items cross-loaded onto more than one factor; however, only two of those items had secondary loadings close to the loadings on their dominant factors. With Principal Axis Factoring the higher the value of each variable (in this case – statement) the stronger the loading on the factor. Four factors emerged from the analysis: (1) Tranquillity and Timeout, (2) Develop Skills and Learn, (3) The Produce and (4) Social Connection.

Table 3. Item loading from Principal Axis Factoring with Varimax Rotation and Kaiser Normalisation.

Principal Axis Factoring: Rotated Factor Matrix [a]				
	Factor			
Statements began, "*I produce food to…*"	**1 Tranquility and Timeout**	**2 Develop Skills and Learn**	**3 Produce Related**	**4 Social Connection**
Experience tranquility	0.817			
To get away from usual life demands	0.767			
Release tension	0.751			
Time to reflect	0.684	0.307		
Relax physically	0.655		0.355	
Mind moves at a slower pace	0.625			
Be close to nature	0.546	0.385		
Enjoy smells and sounds of nature	0.545	0.353		
Be creative	0.485	0.445		
Be along	0.475			
Grow and develop spiritually	0.469			
Remind myself about good times in the past	0.445			
Feel a sense of pride	0.434	0.314	0.307	
Is an important part of who I am	0.433			
Help keep physically fit	0.405		0.312	
Develop my skills		0.772		
Learn new things		0.694		
Feel independent		0.531		
Prove to myself and others that I can		0.520		
Have produce that is healthy for me			0.788	
Have fresh produce			0.751	
Have tasty produce			0.643	
Because I enjoy it			0.504	
To meet new and varied people				0.807
Be with other food producers				0.781
Be with considerate people	0.332			0.659
Share what I learn with others		0.416		0.523
Extraction Method: Principal Axis Factoring. Rotation Method: Varimax with Kaiser Normalization [a].				

[a] Rotation converged in 7 iterations.

Each factor was assessed for their corresponding level of agreement for both home gardeners (n = 355) and community gardeners (n = 17) (Table 4). This assessment was done by combining the mean scores of the statements related to each factor for each respondent. Thus, each respondent had a score for each factor. The agreement levels for the four factors differ somewhat between home and community gardeners. Community gardeners have a slightly higher level of agreement with Factor 2 (Develop Skills and Learn), whereas home gardeners have a stronger agreement with

Factor 3 (The Produce). The main difference, however, is Factor 4 (Social Connection), with the mean response of home gardeners being 'Disagree to Neutral' (2.77), while the mean response of community gardeners is 'Neutral to Agree' (3.54).

Table 4. The comparison of the home and community gardener level of Factor agreement. The colour coding is as follows: yellow for neutral–agree, red for disagree–neutral and green for agree–strongly agree.

	Home Gardeners (n = 355)		Community Gardeners (n = 17)		
Factor	**Mean**	**Level of Agreement**	**Mean**	**Level of Agreement**	**Difference in Means**
1: Tranquillity and Timeout	3.88	Neutral–Agree	3.84	Neutral–Agree	0.04
2: Develop Skills and Learn	3.73	Neutral–Agree	3.94	Neutral–Agree	0.21
3: The Produce	4.70	Agree–Strongly Agree	4.35	Agree–Strongly Agree	0.35
4: Social Connection	2.77	Disagree–Neutral	3.54	Neutral–Agree	0.77
Scale responses: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree.					

Each factor was analysed for correlations with other variables, including gardening consistency, the total number of production methods, gardening experience, years lived in the current house, and the number of social learning sources. Factor 4 (Social Connection) was the only factor to return significant results. Respondents with higher Social Connection values had larger gardens (Spearman correlation: $r_s = 0.235$), greater gardening consistency (Spearman correlation: $r_s = 0.249$), shared food with more different groups of people (Spearman correlation $r_s = 0.232$), believed they saved greater proportions of their weekly fruit and vegetable budget (Spearman correlation: $r_s = 0.336$) and agreed more with the statement, "I produce food to save money" (Spearman correlation: $r_s = 0.209$).

3.1.2. Social Capital

The original social capital scores ranged from zero to five; home gardeners (n = 336) were asked questions about their neighbourhood, while community gardeners (n = 18) were asked questions about their community garden. Out of five, home gardeners had

a median score of three, while community gardeners had a median score of four. When also considering the involvement or lack therefore of respondents in group gardening activities (such as working bees, garden tours, harvest parties or swap meets) the difference between home and community gardeners became more pronounced. Of the home gardeners, 44% had participated or organised a group gardening activity, whereas this was 83% of community gardeners. Indeed the community gardeners were found to have higher 'total social capital scores' (a combination of their median social value scores with an additional point added for any involvement in group gardening activities), than home gardeners (Mann–Whitney U = 5123, n_1 = 20 (community gardeners), n_2 = 355 (home gardeners), P = 0.001, r = 0.22). The Mann–Whitney U test is a nonparametric test of the difference between two unrelated samples (Hawkins 2014). No relationship was found between household social capital scores and the presence of either an elderly family member (over 65), or young children (primary school age or younger), nor was there any relationship found between social capital scores and the respondents' age, how long they had lived in their house or neighbourhood, how frequently they share food, or with any of the four factors. The median length of time the respondents had lived in their house was eight years, while the median length of time lived in their neighbourhood was nine years.

3.2. Food Preservation Practices and Food Distribution

How people use their harvested produce is an important aspect of their food gardening activities. Other than immediately consuming it, food gardeners can either preserve food or distribute some of what they grow to others. When the EG survey respondents were asked whether they experience gluts of crops, 73% either 'Agreed' or 'Strongly Agreed' (n = 367). The respondents were asked to select all the food processing, storing, or preserving techniques they had used within the last year (Figure 2). Seventy percent of the respondents made use of three or more different preservation techniques. Respondents were not asked about food waste, but some did mention trying to avoid food waste in response to the question about why they did or did not store, process or preserve harvested food (Table 5).

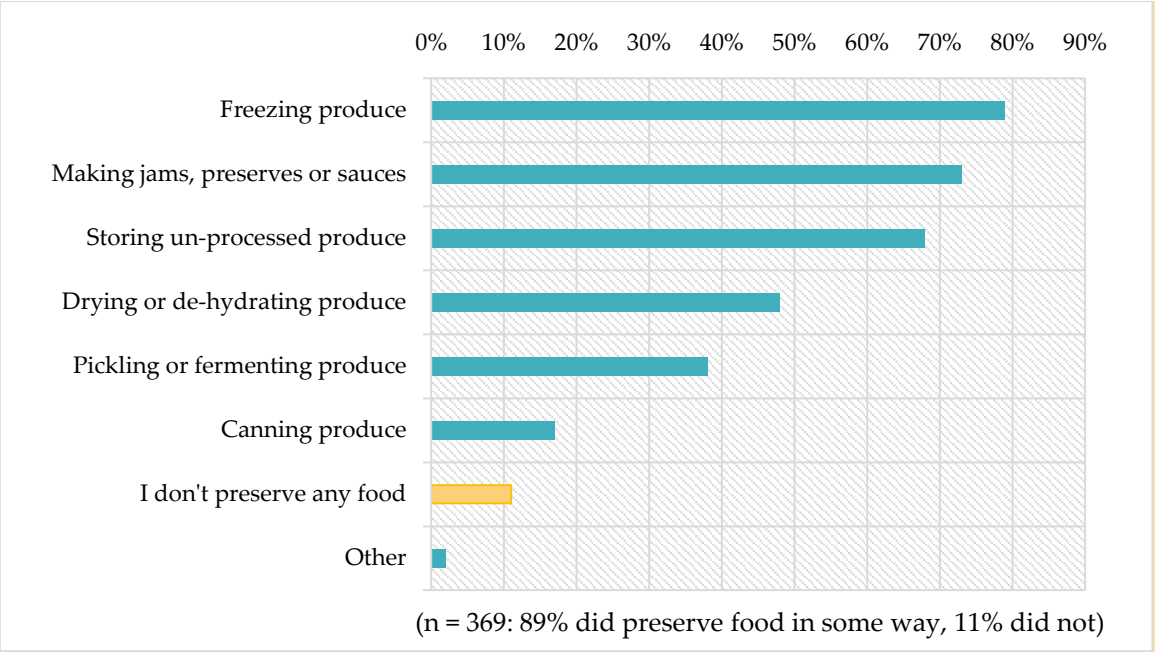

Figure 2. The food processing, storing or preserving techniques used by the Edible Gardens survey respondents in the past year. 'Other' mostly refers to other uncommon methods, for example, salting olives or making wine, beer and cordial. The options were not mutually exclusive.

Table 5. The reasons to and to not store, process or preserve harvested food.

Storing, Processing and Preserving Food			
Reasons to Store, Process or Preserve Food (n = 302)	**%**	**Reasons not to Store, Process or Preserve Food (n = 35)**	**%**
1 Use at a later date	28%	1 Prefer it fresh or consume it all fresh	37%
2 Avoid waste	19%	2 Give any excess away	34%
3 Use in cooking	12%	3 Don't grow enough	26%
4 Overcome a glut of food	9%		
5 The process is interesting and/or enjoyable	8%		
Total percentage of those did store, process or preserve food in some way	89%	Total percentage of those who do not store, process or preserve food	11%

The number of food processing, storing or preservation methods used by the respondents positively correlated with several other variables. Gardeners who used more of these methods were also likely to use a greater number of theoretical gardening approaches (e.g., organic, permaculture, companion planting) (Spearman correlation: $r_s = 0.215$), use a greater number of different physical production methods (e.g., raised garden bed, wicking bed, pots or planters) (Spearman correlation: $r_s =$

0.244), to spend more hours per week growing food (Spearman correlation: $r_s = 0.225$), to have greater gardening consistency (Spearman correlation: $r_s = 0.215$), to believe they save more money (Spearman correlation: $r_s = 0.249$) and finally, to give food to more groups of people (Spearman correlation: $r_s = 0.239$).

3.2.1 Food Distribution

The survey respondents were asked whether they share, gift or donate food they grow to others outside of their household. Most respondents said yes (95%), while only 5% said no. Those who said no were asked why (open-ended question; n = 21) with the most common response being, they "Don't grow enough" (70%).

Those respondents who said yes to food sharing were asked about the frequency of their sharing and who they gave food to (Figure 3). While friends were the most commonly reported recipient of food sharing (42%), a total of 59% of respondents reported giving food away to three or more different groups of recipients. Sharing food to a greater number of recipients was correlated with greater numbers of theoretical gardening approaches (Spearman correlation: $r_s = 0.222$), greater numbers of physical production methods (Spearman correlation: $r_s = 0.288$), greater year-round gardening consistency (Spearman correlation: $r_s = 0.228$) and the belief that they saved more money by producing food (Spearman correlation: $r_s = 0.238$). Those respondents who said yes to food sharing were also asked whether they purposefully grew extra food to share it with others. This question elicited quite a different response, with only 36% answering 'yes', and 64% answering 'no'.

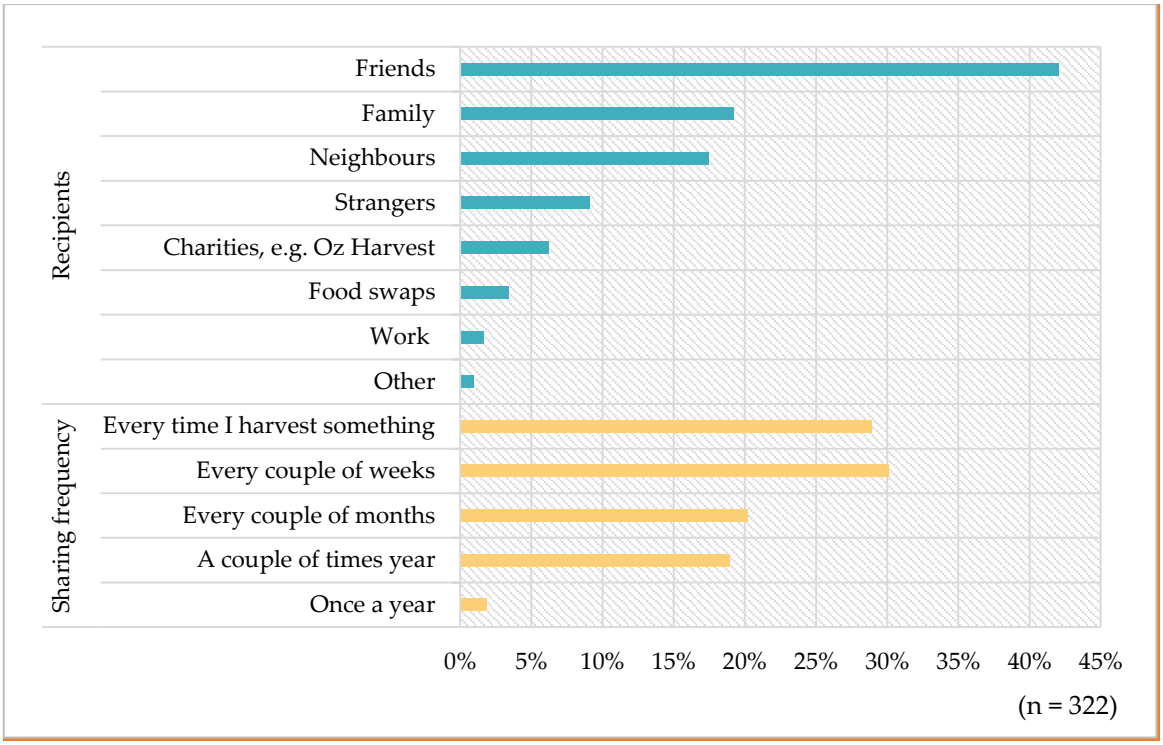

Figure 3. The reported recipients and frequency of food sharing by Edible Gardens project survey respondents. The 'other' recipients refer mostly to selling produce to local cafes or businesses and giving food away to anyone they come in contact with.

As part of the Phase 2 garden data collection, selected participants not only weighed and recorded the different crops they grew, but also recorded, weighed and tracked any food they gave away to others outside of their own household, including who they gave it to. Of the 4202 kg of produce grown and recorded, 12% (501 kg) was given away to others. The proportions of food given away to others included 50% to family, 48% to friends, 1% to both the community and 'other', and less than 1% to food swaps. The food which was given away can be categorised by type: Vegetables, Fruits, Animal Products and Herbs (Table 6). Regarding the frequency of produce sharing of the Phase 2 participants, the majority (87%) of food sharing was occurring at least every couple of weeks, with a further 9% of the sharing occurring every couple of months and 3% occurring a couple of times a year.

Table 6. Tracked food sharing by produce category by EG participants (n = 39) during Phase 2 of the EG project.

Shared Produce Categories	% of the Total Harvest Which Was Shared (by Category)	Most Common Foods/ (by Category) in kg	% of Shared Category
1. Vegetables	55%	Zucchini (80 kg) Tomatoes (54 kg)	34% 23%
2. Fruits	28%	Nectarines (24 kg) Peaches (19 kg)	20% 16%
3. Animal Products	15%	Chicken eggs (89 kg)	100%
4. Herbs	2%	Coriander (1 kg)	54%

4. Discussion

The following discussion is split into three parts: (1) the motivations and value of growing food, (2) the social value of growing food, and (3) the implications for health and wellbeing.

4.1. The Motivations and Value of Growing Food in Urban Areas

The dominant motivations for our home gardeners were the produce (mostly taste and freshness), enjoyment, and health (mostly chemical input concerns and interest in organic food). As comprehensively reviewed by Kiesling et al. (2010), past research into general gardener motivations supplies the following categories: creative expression, health promotion, production, skill-building, and knowledge enhancement, connection to nature, perceived social benefits and as an expression of faith. The majority of both the original and ongoing motivations reported by the EG survey respondents fall into these listed categories (Tables 1 and 2). The few reported motivations not strictly adhering to these categories are saving money, convenience, satisfaction and accomplishment, and enjoyment. Satisfaction and accomplishment may be linked to the listed category of skill-building, and knowledge enhancement, and it is possible that enjoyment fits into the category of creative expression. But both

saving money and convenience appear to remain motivations unique to the practical and productive nature of producing food.

Curiously, both natural connections and environmental considerations were reported by reasonably low percentages of both home and community gardeners. Although ranked 4th and 5th by home gardeners and 6th and 4th by community gardeners, the natural connection was only reported by 15–25% of the total combined survey respondents. Environmental consideration was ranked 11th (just off the list of the top 10 categories) and 8th by home gardeners and 5th and 9th by community gardeners yet was only reported by 12–15% of the total combined survey respondents (Tables 1 and 2). 'Environmental consideration' consisted of references to carbon, food miles, local food, helping the world, sustainability and waste, compost and recycling. A much stronger reference to environmental consideration came from the question of why people store, process or preserve food, with the second highest reason being 'to avoid waste' (19%). Indeed, future research could investigate whether self-grown food is more highly valued than store-bought food and whether self-grown food is, therefore, wasted less.

4.2. The Social Value of Growing Food in Urban Areas

Growing food at home is not always perceived as an inherently social activity, particularly when compared to community gardening. Yet multiple avenues for social connection, value and interaction can be recognised in home gardeners in this study. The first avenue of social connection is via learning sources. The EG survey participants were asked to select all the sources from which they gained knowledge about growing food (n = 381). Out of the nine possible sources, five of them were categorised as 'social' sources—typically from face-to-face interactions (Figure 1). The remaining four sources were categorised as 'less-social' sources—typically lacking face-to-face interactions. Learning from family (65%) and friends (62%) were the two highest listed social learning sources. These results match that of Kiesling et al. (2010), who found that 60% of their respondents reported that their interest in gardening stemmed from the influence of a relative, friend or neighbour. The greater the number of social learning sources someone had, the more likely that person was to use a

greater number of production methods, gardening approaches, irrigation methods, give food to more groups of people and have greater gardening consistency. In short, it appears that additional social learning sources inspire greater diversity in our respondent's food gardens.

The survey also investigated the social capital levels of the respondents. Community gardens have been found to assist in increasing the social capital of members (Kingsley et al. 2006; Twiss et al. 2003), while the relationship between home food gardens and social capital is less understood. Galhena et al. (2013) considered the value of interactions between home gardeners and the community within indigenous cultures. Although a more individual activity, home gardeners did interact with the broader community with exchanges or gifts of produce. It is these interactions that can contribute to the building of social capital (Galhena et al. 2013). The lack of statistical relationship found between household social capital scores and the presence of either an elderly family member (over 65), or young children (primary school age or younger) differs greatly from the results by Martin et al. (2004). We did find, however, that our community gardeners were almost twice as likely to have participated or organised a group gardening activity. By incorporating any involvement in a group gardening activity to each respondent's social value score, the difference in social capital levels between the community and home gardeners became more pronounced with our community gardeners having higher levels of total social capital.

There is a substantial difference in the intra-household and inter-household social connections between home and community gardeners. 'Social connection' was listed as one of the top ten original and ongoing motivations for the home and community survey respondents. The difference lies in what 'social connection' meant to each group. For home gardeners, 'social connection' referred mostly to family and children—an intra-household social connection. These connections were categorised as social during our analysis yet may not be considered particularly 'social' by the home gardeners themselves. For community gardeners, however, 'social connection' referred mostly to community interaction—inter-household social connections. This contrast is further emphasised by the rating of Factor 4 (Social connection), which elicited a

"Disagree to Neutral" response (mean = 2.77 out of 5) from home gardeners and a "Neutral to Agree" response (mean = 3.54 out of 5) from community gardeners. These results suggest that, in general, our home gardeners do not actively value or desire inter-household social connection through food gardening. This finding corresponds with the work by Wise (2014) who found that only 2% of gardeners reported community participation or making friends as reasons to grow their own food.

4.3. Food Preservation and Distribution

As the majority of the EG survey respondents either 'Agreed' or 'Strongly Agreed' that they experienced gluts of crops, there are opportunities for activities with surplus produce. Learning to preserve and store produce is a practical way to even out crop availability (Deppe 2010; Utzinger et al. 1978). Beyond the practical aspects of food preservation, Click et al. (2010) found that food preservation can also be a way to strengthen relationships and connections in addition to being a strong source of empowerment. As most of their participants were taught preservation techniques by a family member or friend, or practised the technique as a family event, these practices often evoked strong emotional memories and responses (Click et al. 2010).

The EG survey respondents were quite prolific with their use of food preservation methods, with 70% using two or three methods in a year. The most common methods were freezing produce (79%), making jams, preserves or sauces (73%) and dry storing produce (68%). Although the sharing of preserved foods was not tracked during the EG project, such products are also likely to be shared, as fresh produce is, with others outside of the grower's household.

Fresh or preserved produce can also be gifted, donated or distributed to others outside of the grower's household. Sharing produce has typically been reported as a low motivator for food gardeners in developed countries (Butterfield 2009; Kortright et al. 2011; Wise 2014), and indeed it did not appear in our lists of either original or ongoing motivations. While it may not be a motivation for people, it certainly appears to be a frequent outcome of growing food. Vitiello et al. (2010) were surprised when nearly all their community garden participants reported sharing their produce with those who were hungry. The strong majority of EG survey respondents reported sharing food

frequently with a range of people. During Phase 2 of the EG project, our participants weighed and tracked the amount of food they shared with others outside of their own gardens (12% of the total harvest). The different reported crop categories (vegetables, fruits, animal products, and herbs) can carry a very different value (both monetary and dietary) per kilogram, thus the crude proportioning of produce sharing by weight alone only tells part of the story of generosity. Sharing with family was reported at a higher rate during Phase 2 garden data collection than was estimated by survey respondents as part of Phase 1. Other studies to weigh and track proportions of harvests shared with others (as part of larger UA yield studies) include Algert et al. (2016), Conk (2015), Pourias et al. (2015), and Zainuddin et al. (2014). These studies all reported greater percentages of food shared with others, between 17% to 35% of their total harvests. The most similar finding was by Algert et al. (2016) who found that although their 12 gardeners shared an average of 30% of their total harvest. The recipients and proportions shared in that study were consistent with our findings from the EG project. Fifty percent of their participants shared produce went to family, 43% to friends and 3% to both charities and co-workers.

Most of the EG survey respondents stated that they did not purposefully grow extra food to share it. The contrast between those who reported sharing food (95%) and those who say they do not grow extra food to share on purpose (64%) could either attest to people's generosity, to their lack of awareness of the quantity of food their gardens produce, or to the lack of reliability of their food production—resulting in a large harvest one year and a low harvest the next. These findings are in agreement with the work of Kortright et al. (2011) who established that the majority of their gardeners purposely chose not to grow more food than they believed their own household could consume. Yet their remaining participants reported purposely growing and sharing their excess produce to initiate and maintain social relationships with others (Kortright et al. 2011).

The EG gardeners' sharing of food typifies the growing awareness and popularity in South Australia of giving free excess food away to others. Other examples of this South Australian generosity include 'Grow Free' and 'Ripe Near Me'. Grow Free is a recent

South Australian initiative of carts placed in public places where people can leave fresh produce, seeds, and seedlings to give away to others. The items are not valued in any way. There is no swapping, bartering or prices, people simply give what they can and take what they need. As of April 2018, there were 137 Grow Free carts listed across South Australia (http://www.growfree.org.au/our-story/). Ripe Near Me was started in 2012 by two Adelaide based 'foodies' (people with a particular interest in food). They wanted to create a website to help people connect, find, grow, share and sell fresh and very local produce. The site hosts a map covered in different markers pinpointing the locations and describing the ripeness of available foods. Anyone can register to post produce they have grown themselves, or even produce they have spotted growing in other locations (https://www.ripenear.me/). While urban food producers should still endeavour to improve their ability to produce food effectively and predictably, the various channels enabling food distribution means the wider community can benefit from inevitable food surpluses.

4.4. Implications for Health and Wellbeing

'Health' was listed as one of the dominant motivations of the survey respondents, referring mostly to concerns over chemical inputs and interest in organic foods. In addition, Factor 3 (The Produce) related strongly to valuing produce which was healthy, fresh and tasty. The healthiness of the food grown was a strong consideration of our survey respondents. The practical merits of this valued "healthiness" have also been reported to improve the dietary intake of fresh produce and improve nutrition from participation in community gardens (Alaimo et al. 2008; Carney et al. 2012) and home gardens (Kortright et al. 2011).

While several of the EG survey motivations reference mental health and wellbeing, these considerations were not rated particularly highly in either the original or ongoing motivations. Yet there is a difference between a motivation for a behaviour and an outcome or benefit from a behaviour. Of the four value factors identified, Factor 1 (Tranquillity and Timeout) is inherently related to mental health and wellbeing. Key value statements in Factor 1 reference tranquillity, getting away from usual life demands, releasing tension, time to reflect, relaxing physically, the mind moving at a

slower pace and connection to nature. Both the home gardeners and community gardeners rated this factor similarly and reasonably highly at 3.88 out of 5 and 3.84 out of 5 respectively (these scores sit at the higher range of the 'Neutral to Agree' level of agreement).

Another factor in the potential to relate to mental health and wellbeing is Factor 4 (Social Connection). As discussed above, the social connection factor was valued more highly by the community gardeners than by the home gardeners. Nevertheless, this does not mean that home gardeners do not value or participate in other avenues of social connection, for example, via the social learning sources or food distribution. Indeed Walsh (2015) found growing food to be both a connection to gardeners' childhoods and a contributor to each gardener's sense of identity.

The final aspect of this research related to health and wellbeing is happiness. Enjoyment was another of the dominant motivations for the survey respondents, with many descriptions of love, happiness, and contentment. This speaks to past research where gardens, in general, are described as 'labours of love' (Watts 2015). Indeed in the study based in Florida, USA, by Zahina-Ramos (2013), feelings of happiness, relaxation, and satisfaction were more highly valued than the produce itself. Experiencing nature has already been found to have a positive relationship with happiness (MacKerron et al. 2013; Zelenski et al. 2014). Our results suggest that a similar relationship is possible within urban food gardens.

The combined results from this research regarding health and wellbeing, social connection and happiness support the premise that engagement in home or community food gardening may provide a preventative or supportive role for gardeners' health and wellbeing, regardless of whether it is a conscious motivation for participation. Soga et al. (2017) and Wood et al. (2016) also advocate engaging in urban agriculture as a form of preventative healthcare: encompassing general health, mental health, and social health. We recommend two key areas for future research, (1) food waste and whether self-grown food is more highly valued than store-bought food and thus is wasted less, and (2) how the non-monetary benefits of UA compare with the costs or benefits of food gardening measured in other ways, such as productivity.

5. Conclusions

Outwardly, the EG home gardeners were predominately motivated by the produce, health, and enjoyment, while the EG community gardeners were more motivated by enjoyment, connection to others and the produce. Of the other top ten motivations, saving money and convenience were the two found to be unique to the productive and practical nature of producing food.

The social connection was the greatest difference between the home and community gardens, with community gardeners being more strongly motivated by social connection with people outside of their own households. The community gardeners were found to have higher levels of total social capital than home gardeners and were approximately twice as likely to engage in a group gardening activity. Although home gardeners did not appear to actively value or desire inter-household social connection through food gardening, this does not mean they do not value or participate in other avenues of social connection, such as via social learning sources or by sharing food with others. Greater numbers of social learning sources were also found to inspire greater garden diversity. With regards to sharing food with others, 95% of the survey participants reported sharing food with others, although the majority (64%) did not set out to grow food to share. Of the Phase 2 participants who collected data on their own food gardens, a total of 501 kg (12% of everything they grew) was given away, typically every couple of weeks, to family, friends and the community. The wide range of channels facilitating sharing of surplus food provides growers with unpredictable yields or surplus harvests to contribute to the wider community.

Although mental health and wellbeing did not rate particularly highly as either an original or an ongoing motivation for our gardeners, there is a suggestion of deeper values as evidenced by the presence of factor items related to Tranquillity and Timeout (Factor 1). This, together with the overt sociability of community gardeners, the 'subtle sociability' of home gardeners (via social learning sources and food distribution), the strong valuing of both health and enjoyment, and the demonstrations of generosity, lead us to believe that participating in home or community food gardening may act as a supporting or preventative mechanism for resilient health and wellbeing.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, List S1: List of relevant survey questions used in the EG online survey; List S2: List of REP items used in the EG project online survey.

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6 Productivity, Resource Efficiency and Financial Savings



Overview

The research presented in this chapter is the culmination of results on the productivity, resource efficiency (including water use and financial sustainability) and social value of urban food gardens in South Australia. Although home food gardens are the most dominant form of UA in Australia, they remain the least understood. And yet as the dominant form of urban agriculture, the diverse stock of existing home food gardens represents the greatest potential influence on our future urban food security and sustainability.

Without consistent and comparable in-field collected data on home food gardens, there is no knowledge on which to base sustainable improvements, or to help upscale UA for the development of a commercial UA industry. The research in this chapter builds on all earlier chapters, demonstrating a rigorous method to study and collect data on existing urban food gardens, including measurement techniques, units of comparable values, garden area categories and water use efficiency equations.

Of the data presented, the inputs measured by citizen science participants included time spent on various garden related activities, all costs, and all water use from different sources and irrigation methods. The reported outputs included crop yields, in addition to the retail value and nutritional content of the harvests. Detailed results are presented on the whole gardens, and on the five main "tech-crop" (garden area) categories - including the first ever reported water use efficiency results on existing home food gardens. New findings on the current state of urban food gardens include

insights into their productivity, resource efficiency and financial sustainability, including estimates of return on labour and pay-back on capital expenditure. Results pertaining to the scale and instensity of food gardens have implications planning and optimising effective UA design. Gardeners can also use these data to match their individual motivations and challenges to the trade-offs of different "tech-crop" (garden area) categories and identify the most suitable approaches for themselves to use. The results represent the most comprehensive dataset on home food gardens to date, and allow practical, evidence-based recommendations to improve garden productivity and enhance the viability of UA.

This chapter contributes directly to the following research objectives:

2. *Develop and implement a novel approach to enable widespread measurement of urban agriculture input and yield data on existing urban food gardens.*

3. *Clean, manage and analyse collected data from both Phase 1 and 2 to gain an in-depth understanding of current urban food gardens in South Australia.*

4. *Respect the reciprocal relationship with the 'citizen scientists' (survey respondents and selected phase 2 participants) who contributed data to the Edible Gardens project.*

This chapter is based on a paper submitted and currently under review by the journal PLOS ONE. Thus this chapter will differ slightly from the final published version. The manuscript was co-authored by my Principal Supervisors, Dr. James Ward and Dr. Philip Roetman from the University of South Australia.

Author Contribution: Conceptualisation, Methodology & Investigation by G.P., J.W. and P.R.; Statistical Analysis by G.P., J.W. and P.R.; Writing-Original Draft Preparation by G.P.; Writing-Review & Editing by G.P., J.W. and P.R.; Supervision by J.W. and P.R.; Funding Acquisition by P.R.

The format of this paper has been altered for consistency with the rest of the thesis.

Paper 5: Productivity, Resource Efficiency & Financial Savings: An Investigation of the Current Capabilities and Potential of South Australian Home Food Gardens

Abstract

As the dominant form of urban agriculture in Australia, existing home food gardens potentially represent a significant resource in the context of future urban food security and sustainability. However, a severe lack of in-field data available has hindered our understanding of the form and function of home food gardens and prevents the development of potential sustainable improvements. Building on previous publications using South Australia as a case study, this research presents a comprehensive collection of in-field input and output data, providing deeper insight into the productivity, resource efficiency and potential financial savings of home food gardens in this state. A group of 34 citizen science participants measured inputs, including time spent on various garden related activities, financial costs, and all water use from various sources and irrigation methods. Measured outputs included crop yields, from which retail value and nutritional content were then derived. Productivity and resource efficiency results are reported, in addition to estimates of return on labour and financial investment. We present, for the first time, water use efficiency calculations for existing home food gardens and compare them with similar calculations for conventional agriculture, allowing UA's contribution to a sustainable food supply to be better assessed. The paper constitutes a field-demonstrated, comprehensive methodology for continued and consistent data collection on all forms of UA. The results represent the most comprehensive dataset on home food gardens to date, and allow practical, evidence-based recommendations to improve garden productivity and enhance the viability of UA. Smaller gardens were found to be more intensive than larger gardens, requiring higher inputs, but also returning higher outputs per unit area. With this new dataset, work can now begin to investigate ways in which to nurture and encourage sustainable improvements and potentially increase the contribution of urban food production for the future.

Keywords: urban agriculture; urban food production; garden efficiency; water use efficiency; food security; economic sustainability; urban environments; citizen science; home gardens; South Australia;

1. Introduction

Anticipation in the potential of urban agriculture intensifies as the global human population continues to grow, and we begin to face the challenges of feeding more people with limited natural resources. Urban agriculture (UA) is widely anticipated in our collective vision of a sustainable urban future, yet its potential contribution to sustainability and food security is poorly quantified. There is a large-scale lack of knowledge regarding many of the practicalities of UA, and several demands for an increase in field-based data collection on UA have been made (Kirkpatrick et al. 2018; Pourias et al. 2015; Taylor et al. 2013; Ward et al. 2014; Wise 2014). Without such data, there is no knowledge on which to base sustainable improvements or to help upscale UA for a greater future contribution to urban food security. At the local level, both households and local councils are interested in whether growing food can help people to save money – thereby reducing their cost of living. Home food gardens are the most common form of urban food production in Australia (Wise 2014) and yet their productivity, resource efficiency and potential financial savings are still relatively unknown. We have a clear need to better understand UA as it currently exists in our urban areas.

This paper presents field-collected data from "Edible Gardens", a state-wide citizen science project of the Discovery Circle and the University of South Australia. The work presented here is the culmination of results on the productivity, resource efficiency (including water use and financial sustainability) and social value of urban food gardens in South Australia. This research builds on four previously published papers (Pollard et al. 2017; Pollard et al. 2018a; Pollard et al. 2018b, 2018c). A review and critical evaluation of past UA yield research led to an investigation of the potential for a citizen science approach (Pollard et al. 2017). The main limitations of past research were identified, including: monitoring of purpose-built experimental gardens rather than existing food gardens, the overuse of theoretical extrapolations of UA yields, the

oversight of water as a fundamental input for UA, the lack of labour data and the subjectivity of yields required to assess whether UA is financially or nutritionally worthwhile. The design of the Edible Gardens project centred around a citizen science approach as an effective way to overcome many of the challenges inherent in practical UA research, critically allowing the focus to be on the performance of real-world, existing food gardens and gardeners. Due to the paucity of information on UA water use, the second paper conducted a PRISMA systematic review into research on water use and water use efficiency of UA (Pollard et al. 2018b). No scientific studies were found to have collected water use data on existing urban food gardens, such as home gardens. South Australia was explored as a case study because of its dry climate and widespread UA activity. The variety of water sources, water costs and irrigation methods available to South Australian food gardeners demonstrated some of the practical difficulty that would be faced if measuring the water use of UA. Four new equations were then proposed to calculate various forms of UA water use efficiency. The development of the water use measurement method used by the Edible Gardens project was described, before other water and yield measurement methods were recommended.

A third paper explored the economic sustainability of home food gardens via results from the initial online survey questions relating to the physical, practical and economic aspects of respondents' food gardens (Pollard et al. 2018c). The results revealed a rich diversity of cultivation techniques, water sources, irrigation methods, garden sizes, estimated labour requirements and costs of urban food gardens in South Australia. While saving money was a top motivator for many of the respondents, it remained unclear whether 'growing your own' could help households to save money. Comparison with a theoretical optimised urban garden model highlighted the gap between UA theory and practice. The fourth and most recent paper presented results from the online survey on questions relating to the motivations, values, social value, food preservation and food distribution of the respondents (Pollard et al. 2018a). Aspects of home and community gardeners were compared, with some differences identified in their top motivations for producing food. Overall, the key difference between the two groups was social connection. The community gardeners

demonstrated what was termed 'overt sociability' compared to the 'subtle sociability' of the home food gardeners.

Building on the foundation of the four preceding papers, the current study presents a rigorous research methodology for collecting input and output data on existing urban food gardens, with an emphasis on home food gardens. The measured inputs included time spent on various garden related activities, all costs, and all water use from various sources and irrigation methods. While the measured outputs included crop yields and the retail value and nutritional content of the harvests. Diverse forms of food garden activity are considered by these methods, including orchard production and the keeping of urban livestock. This research provides a new and replicable method as well as results giving comprehensive insight into the form and function of existing home good gardens in a South Australian context. Productivity and resource efficiency results are reported, in addition to estimates of return on labour and financial investment, and for the first time, water use efficiency results are presented for existing home food gardens. There was also scope for consideration of the influence of scale in home food gardens and the potential relationship with intensity of production or resource requirements. Implications of these findings include new ways for gardeners to decide upon suitable gardening setups, and a practical, evidence-based rationale for improving and optimising UA towards broader goals of urban sustainability, accessibility and food security.

2. Materials and Methods

The Edible Gardens project ran from the end of 2016 until mid-2018. It received ethical approval from the University of South Australia in 2015 (Protocol number 0000034940). The project had two parts, the first an online survey and the second a period of field-based garden data collection by selected "citizen scientists" (members of the public who volunteered and received guidance on how to collect input and output data on their own food gardens). All forms of urban food production were welcome, from growing fresh produce in different ways to the keeping of urban livestock such as poultry, bees or fish. The project was open and promoted to home, community and school gardens across South Australia. The Phase 1 online survey was open to South

Australian residents over the age of 18. The in-depth survey collected a variety of base garden data, estimates of resource use and insights into food garden experiences. From September 2016 until April 2018, 402 South Australian residents completed the survey. The design and results of the online survey have been previously reported in detail (Pollard et al. 2017; Pollard et al. 2018a; Pollard et al. 2018c).

Phase 2 of the project involved selection of survey respondents to collect data on their own food gardens. 232 (58%) of the survey respondents volunteered to be part of this phase, and of these, 105 were selected in an attempt to cover a wide variety of garden size, gardener age, gardening experience levels, types of food gardens and water sources. Home gardeners showed the most interest in the project. Of the gardeners selected, 71 home gardens and 2 school gardens registered with the project and requested data collection toolkits. Interestingly, although 20 community gardeners completed the online survey, none registered to participate in Phase 2. Registration for Phase 2 was done online and involved nominating the number of garden "areas" for which the gardener was willing to collect data (with a maximum of four per garden), uploading a photo and describing the whole food garden. For each nominated garden area, they reported its size (area under production), cultivation technique, typical crop/s, water source/s, irrigation method/s, and position on the land block. Registered gardeners were posted a data collection toolkit (as reported in (Pollard et al. 2017)) which was customised to suit their food garden, particularly their water sources and irrigation methods (which dictated what type, and how many, water meters to supply). The toolkits included instructions, data sheets and measurement tools. The instructions and data sheets were based upon the Harvest Count section of the Farming Concrete project developed by Gittleman et al. (2012). After providing the base garden data (area under production, cultivation method, water source, irrigation method, etc.) the participants were asked to measure five variables on an ongoing bases: 1) Time spent on all food-garden related activities; 2) money spent on food-garden related purchases; 3) all irrigation applied (mains, rainwater, bore/grey water); 4) harvested crop yields and; 5) tracking any food shared with others outside of the household (or school). Participants were able to collect data for as short or as long a duration as they wished, although longer participation was encouraged.

Participants entered their data into the Edible Gardens project's online system (for a detailed description please refer to (Pollard et al. 2017)). The data was cleaned and managed by the research team (the authors). Registered gardens with less than 30 days of data collected, less than 30 data entries or lacking record of any of the three inputs (time, money and water) were removed from the dataset. Statistical analysis was conducted using IBM SPSS software and Microsoft Excel. Three forms of supplementary data were collected by the research team. The first was tracking the retail value of different fresh foods over the course of the project using data collected from two supermarkets, a national retailer and a state-based retailer. The average retail price from the two supermarkets at the time of reported harvest were applied. Although many of the participants reported using organic growing approaches, certified organic retail prices for food products were considered inappropriate. Nutritional information, including energy, protein and percentages of edible parts of each crop were collected from the Food Standards Australia New Zealand (FSANZ) online database - Nutrient Tables for Use in Australia (NUTTAB) (Food Standards Australia New Zealand 2017). The third form of supplementary data was rainfall data for the duration of each participant's involvement. This was collected from the Australia Bureau of Meteorology's Online Climate Database (Bureau of Meteorology 2018) using the closest weather station to each garden with available data for their data collection period. Rainfall data was added to irrigation data, as recommended by Pollard et al. [7] to calculate total water received by plants, enabling greater comparison of the water use results from this study with those from (future) studies in wetter or drier climates.

Owing to variability in garden size and duration of participation, most of the values in this paper are presented as the value per square metre, per 30 days. Presenting results as values per square metre (or square yard) is typical of UA research. The duration of data collection of past studies has varied considerably yet studies tend not to normalise to a standard length of time. For example, Stall (1979) reported a yield of 6.79 kg/m^2 (from 8 months), Cleveland et al. (1985) reported a yield of 1.24 kg/m^2 (from 2.5 years) and 2.31 kg/m^2 (from 3 years), Codyre et al. (2014) reported a yield of 1.43 kg/m^2 (from 1 year) and Zainuddin et al. (2014) reported a yield of 0.35 kg/m^2 (from 3 months). This

makes comparisons with past results challenging. Introducing time as an additional denominator allows for clearer comparisons than currently possible, across studies of different durations.

3. Results

Overall, data was collected on 34 home gardens, containing 93 individual garden areas. Data collection occurred across South Australia during the period from November 2016 to June 2018, although not all gardens collected data for this whole period. Across all participating gardens, total duration of data collection was 7,565 "garden-days" or 252 "garden-months". The total combined area under production was 3,161m^2 and the total harvested yield was 3,479kg of fresh vegetables, fruits, herbs, eggs, fish and honey. There was a wide variety of cultivation techniques and typical crop combinations (denoted "tech-crops") involved across the different gardens; for a summary of all the project data please refer to Supplementary Table 1. Results from all garden areas (and all tech-crops) are included in the results pertaining to whole gardens. This paper also presents individual results on the five dominant tech-crop categories:

1) Bed-orch: In-ground orchard (fruit trees)
2) Bed-veg/herb/other: In-ground bed producing vegetables, herbs and 'other' crops
3) Chkn-egg: Chickens kept for egg production
4) Raised-veg/herb/other: Raised bed producing vegetables, herbs and 'other' crops
5) Wick-veg/herb/other: Wicking bed producing vegetables, herbs and 'other' crops

There were also three aquaponics systems, totalling more than 430 data entries. However as there were only three systems, these results are not comparable with the other more prolific main tech-crop categories and so were not included in the individual tech-crop analysis. The aquaponics data collected will be part of future research.

The results presented here are considered first from the perspective of the whole gardens and then individual comparisons are made between the five main tech-crop

categories, with some direct comparison of results to previous research. Of the citizen scientists responsible for the garden data collection, 24 were women and 10 were men, 33 owned (or had mortgages on) their own homes while only one rented. The majority (27) of the participants shared at least some of the food they grew. From this point, the Edible Gardens project will be referred to as "EG".

Whole Garden Results

The home food gardens involved produced a wide variety of vegetables, fruits, herbs and animal products. Examples of the most common crops/products were: tomatoes, strawberries, parsley and chicken eggs, while some of the more unusual crops included: doughnut peaches, Armenian cucumbers, shisho leaves and tromboncinos. For the full list of harvested crops please refer to Supplementary Table 2. The total yield harvested was 3,479kg with an estimated supermarket retail value of AUS$28,076. Yields varied considerably among the EG gardens, ranging from 0.02 kg/m²/30 days to 1.42 kg/m²/30 days. Exactly 50% of the EG gardens produced yields of less than 0.200 kg/m²/30 days, while 24% managed to produce higher yields of more than 0.500 kg/m²/30 days (Figure 1).

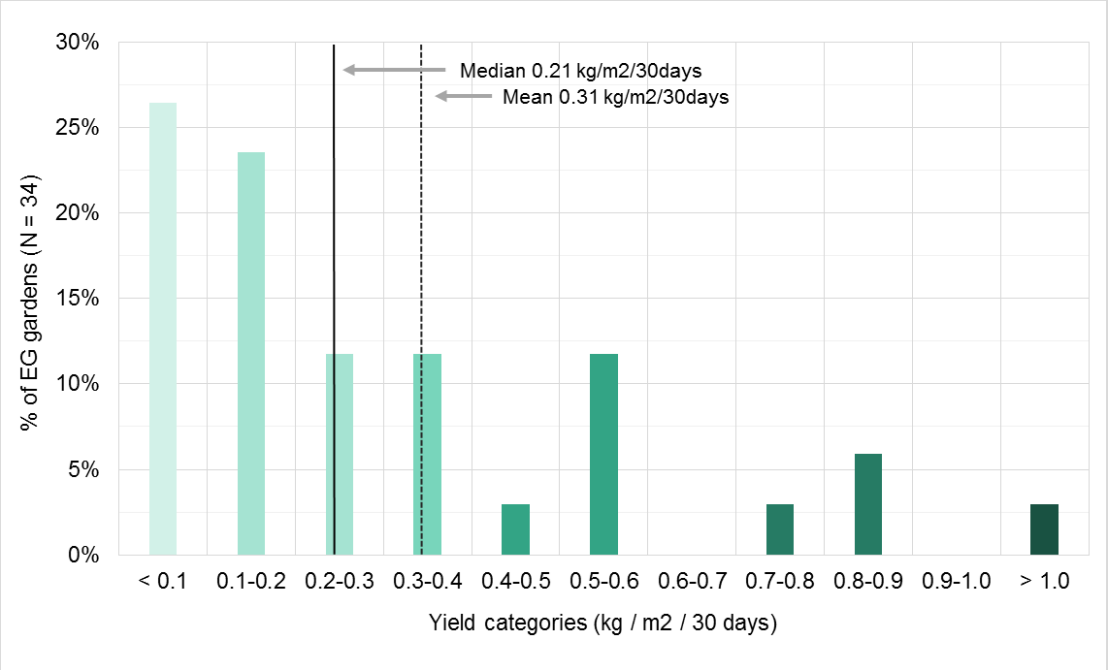

Figure 1. The EG garden yields per square metre per 30 days.

Previous research has also noted the wide variability of yields among individual gardens (Algert et al. 2014; Codyre et al. 2014; Conk et al. 2016; Pourias et al. 2015; Vitiello et al. 2009; Zainuddin et al. 2014). Table 1 compares the EG yield results with the yield results of those previous studies which explicitly reported area under production and their duration of data collection. When measuring the year-round inputs and outputs of urban food gardens, time becomes an important consideration to account for natural cycles of more and less productive times of the year. Table 1 presents the results of this study, both for the combined yield (for all five tech-crops) and also for only the vegetable-growing categories, for comparison with previous studies that considered mostly vegetable cultivation.

Table 1. A comparison of average yields (kg/m^2) and (kg/m^2/30 days) among previous research and the EG results. These results were calculated for the previous studies.

Year	Project name / Authors	No. of gardens	Location	Reported yield (kg/m^2)	Average yield (kg/m^2/30 days)
1979	Stall (Stall 1979)	1	Florida, USA	6.79	0.850
1980	Stephens et al. (Stephens et al. 1980)	2	Florida, USA	2.70	0.450
1985	Cleveland et al. (Cleveland et al. 1985)	2	Arizona, USA	1.20	0.020
2014	CoDyre et al. (Codyre et al. 2014)	50	Ontario, CAN	1.43	0.006
2014	Zainuddin & Mercer (Zainuddin et al. 2014)	15	Melbourne, AUS	0.35	0.020
2016	Algert et al. (Algert et al. 2016)	8	California, USA	6.00	0.188
This study	*all five main tech-crop areas*	34	South Australia, AUS	2.70	0.370
This study	*only veg/vegh/herb/other areas*	34	South Australia, AUS	3.40	0.470

With regard to how much home gardens typically contribute to a household, Table 2 compares the results from a survey question previously published by Pollard et al. (2018c), with that of an older study from 1975 by Halkett (1976). The main difference between these two sets of results lies in the category 'Less than 5%'. We expect that this is due to our creation of the two additional categories, 'Unsure' and 'break even'. Interestingly, the total proportion of respondents confident that they offset a

reasonable proportion (>5%) of their fruit and vegetable bill remains similar between the current cohort (38%) and that of the 1975 study (34%).

Table 2. A Comparison of the Edible Gardens survey question on households saving money and a similar question from the 1975 Adelaide study by Halkett (1976) on household fruit and vegetable requirements.

Percentage of weekly household fruit and vegetable budget	Count	% of total (n = 374)	% of total (n = 430)	Count	Percentage of household fruit and vegetable requirements
None	79	21%	22%	96	None
Less than 5%	52	14%	46%	198	Less than 5%
6 - 25%	62	17%	21%	91	6 - 25%
26 - 75%	64	17%	8%	33	26 - 75%
Over 75%	14	4%	5%	12	Over 75%
Unsure	55	15%	-	-	No comparable category
Break even	48	13%	-	-	No comparable category

Of the 34 consistent gardens involved, their total area under production ranged from 4m^2 (smallest), a median size of 49m^2 and through to 731m^2 (largest). In general, increasing the size of the area under production had a negative correlation with many of the inputs and outputs per unit area (Figure 2). These included: ongoing costs (including the cost of mains irrigation) (r_s = -0.456, N = 34, p = 0.007), labour (r_s = -0.718, N = 34, p = 0.001), applied irrigation (r_s = -0.479, N = 33, p = 0.005), total water (W) (r_s = -0.453, N = 33, p = 0.008) in addition to lower yields (r_s = -0.578, N = 34, p = 0.001) and retail value (r_s = -0.678, N = 34, p = 0.001).

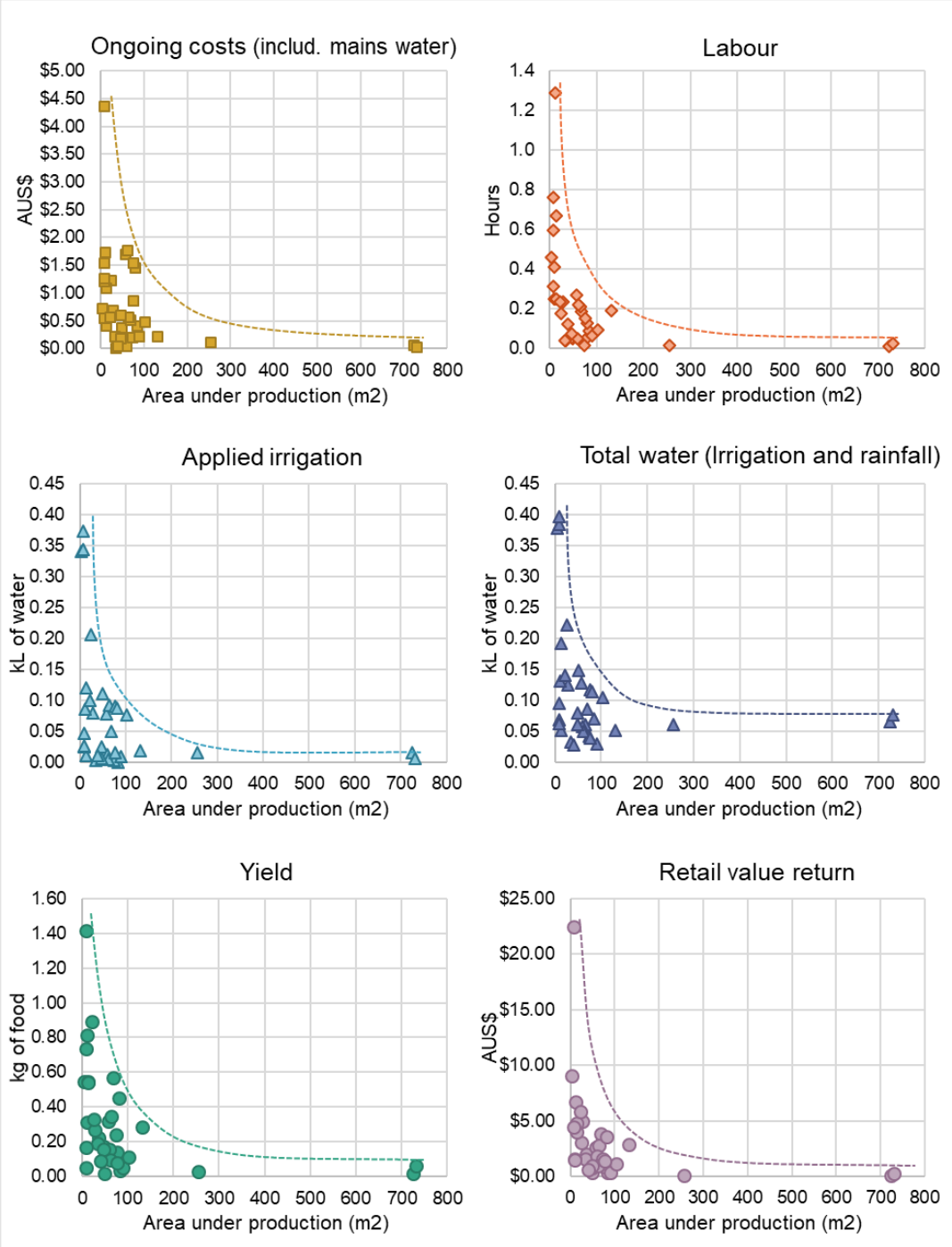

Figure 2 Scatter plots of the negative correlation between area under production and the inputs and outputs. All values are presented as per square metre per 30 days. The lines represent the upper envelope of the results.

The number of (more philosophical) gardening approaches (for example, organic practices, permaculture, traditional digging and tilling, making own compost, biodynamic practices, no-dig etc.) was found to have a negative correlation with both yield kg/m²/30 days (r_s = -0.529, N = 33, p = 0.002) and retail value AUS$/m²/30 days ($r_s$ =

-0.521, N = 33, p = 0.002). The total number of tech-crop categories present in a single food garden (data collected from the EG survey, therefore minimum possible tech-crop areas was one, while the maximum was nine) was also negatively correlated with labour in hours/m²/30 days (r_s = -0.403, N = 34, p = 0.018) and retail value AUS$/m²/30 days ($r_s$ = -0.378, N = 34, p = 0.027).

Size categories were applied to test for differences: <20 m², 20-50m², 50-100m², 100-800m². No statistical difference among the garden size categories was found in relation to applied irrigation (kL/m²/30 days), total water per m²/30 days, in the gardener experience or gardening consistency. Significant differences were, however, found among the ongoing costs, hours spent, yield, retail value and the number of social learning sources. Most of the differences were found between the smallest garden size <20m² and the other garden sizes. The statistical results are outlined below.

There were differences in ongoing costs AUS$/m²/30 days (H(3) = 11.38, p = 0.01, ε^2 = 0.34 (relatively strong)), labour (H(3) = 19.41, p = 0.001, ε^2 = 0.59 (strong), yield kg/m²/30 days (H(3) = 9.19, p = 0.02, ε^2 = 0.30 (relatively strong), retail value return AUS$/m²/30 days (H(3) = 13.35, p = 0.004, ε^2 = 0.41 (strong), and in the gardener's number of social learning sources (H(3) = 12.31, p = 0.006, ε^2 = 0.39 (strong)). The strength rankings of the Kruskal Wallis analyses are based on the interpretation by Rea et al. (2014). Applying a Bonferroni correction found that garden size category <20m² had higher ongoing costs ($1.20) than size category 100 - 800m² (*Mdn.* = $0.11, p = 0.011), required more time (*Mdn.* = 0.46 hours) than the other four size categories, 20 - 50m² (*Mdn.* = 0.10 hours, p = 0.006), 50 - 100m² (*Mdn.* = 0.11 hours, p = 0.003) and 100 - 800m² (*Mdn.* = 0.02 hours, p = 0.001), returned a greater yield (*Mdn.* = 0.55kg) than 100 - 800m² (*Mdn.* = 0.06kg, p = 0.022) and returned a higher retail value (*Mdn.* = $4.47) than 50 - 100m² (*Mdn.* = $1.46, p = 0.03) and 100 - 800m² (*Mdn.* = $0.29, p = 0.005). The Bonferroni correction also revealed the gardeners of garden size category <20m² to use less social learning sources (*Mdn.* = 1 social learning source) than the following size category 20 - 50m² (*Mdn.* = 3.5 social learning sources, p = 0.005).

The median volume of irrigation applied to the entire EG food gardens was 20L/m²/30 days. For only those areas producing vegetables, herbs and other, the median volume

over double that, at 52L/m²/30 days. Of the total 690.8kL of irrigation applied, 71% was mains water, 30% was collected rainwater and 5% was bore or grey water. Natural rainfall on the garden areas constituted between 4% - 94% (*Mdn.* of 54%) of the total water (combined applied irrigation and rainfall) for each garden. As one of the only previous studies to measure their water use, Cleveland et al. (1985) reported the net return for each dollar spent on water as USD$8.80 and USD$7.75 for their two gardens. Our net return per dollar spent on irrigation (assuming the cost of mains water was applied to all irrigation including rainwater and bore/grey water) was between $-41.53 (with some gardens running at a loss) to $169.95 with a median of $13.46 (N = 32 gardens with irrigation data). Cleveland et al. (1985) also reported water to be their single largest expense at almost 30% of their total costs. This differed slightly from the EG results, with irrigation contributing between 3% to 90% of total costs, with a median of 23% (N = 27 gardens with cost data). Statistically, greater total water (*W*) was positively correlated with greater yields ($r_s = 0.514$, N = 33, $p = 0.002$) and retail value ($r_s = 0.535$, N = 333, $p = 0.001$).

WUE is defined as, "a measure of how efficiently production systems convert water (rainfall and/or irrigation) into a harvestable yield or into money" (Pollard et al. 2018b). Using the equations proposed by Pollard et al. (2018b), we calculate different forms of water use efficiency (WUE). The values for simple gross (WUE_{gross}), nutritional (WUE_{nut}) and financial (WUE_{fin}) WUE were calculated for each participating garden. Figure 3 charts each of the WUE values and includes the WUE values of Cleveland et al. (1985) as previously calculated (Pollard et al. 2018b), and the average WUE_{gross} of related crops from Mekonnen, Mesfin M et al. (2011). No statistical difference was found in any of the WUE values and the different garden size categories. WUE_{fin} was however, positively correlated with labour (hours/m²/30 days) ($r_s = 0.479$, N = 33, $p = 0.005$) and negatively correlated with total area under production ($r_s = -0.414$, N = 33, $p = 0.017$), while WUE_{nut} was negatively correlated with total water (kL/m²/30 days) ($r_s = -0.438$, N = 33, $p = 0.011$).

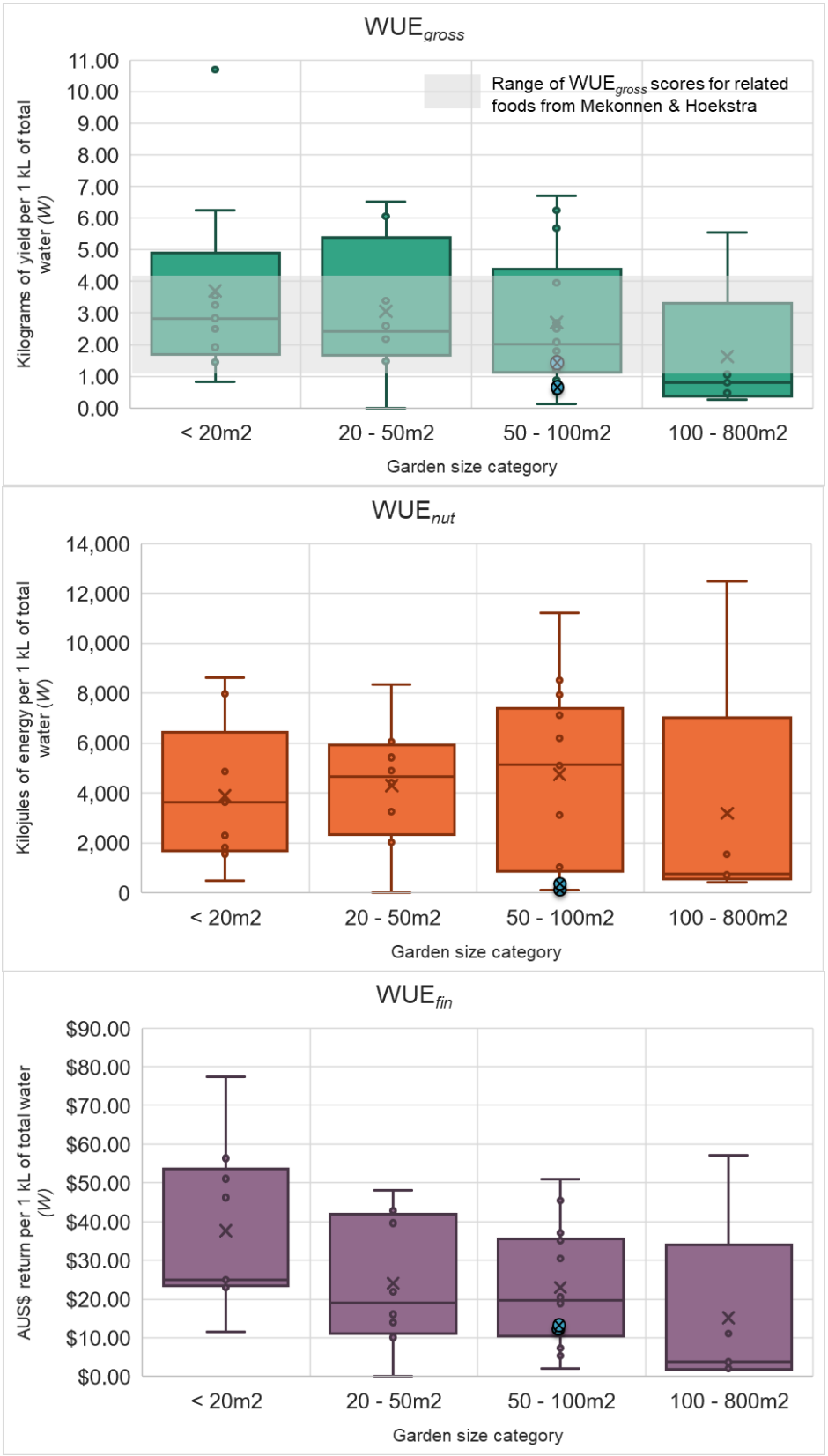

Figure 3. The WUEgross, WUEnut and WUEfin results for the garden size categories. The blue circles represent the WUE values of the two gardens from the Cleveland et al. (14) study as previously calculated [7], and the dotted line represents the average WUEgross value for vegetables, roots & tubers and fruits from Mekonnen and Hoekstra (24).

Participants tracked all time spent on various food-garden related activities. Table 3 displays the different activities and the total and percentages of time spent. The main activities were: harvesting (31%), irrigating (all kinds combined) (20%), and then livestock care and weeding/pruning (both 8%). 'Other' was used as a catch-all for irregular activities. Greater time invested (hours)/ m^2/30 days was positively correlated with greater irrigation ($r_s = 0.570$, N = 33, $p = 0.001$) and total water (W) ($r_s = 0.531$, N = 33, $p = 0.001$), but greater time also returned higher yields ($r_s = 0.637$, N = 34, $p = 0.001$) and retail value ($r_s = 0.738$, N = 34, $p = 0.001$). As reported previously by Pollard et al. (2018b) the EG participants used a variety of different irrigation methods to water their gardens. Cleveland et al. (1985) estimated having spent over 50% of their total time watering their two gardens by hand. We compared this with those EG gardeners who applied water via hand-watering and watering via drippers or sprayers but did not utilise automatic irrigation systems (N = 25). Time spent watering ranged from 13% to 79% with a median of 37% of all time recorded. Participants were instructed to log time spent physically irrigating or turning on/moving watering systems but not the length of time an irrigation system was left running (if the gardener was not in the garden). For some of the gardens or areas with completely automated irrigation systems, those participants were able to log zero minutes for irrigation.

Table 3. All monitored garden-related activities and time spent on each (ordered by % of total)[1].

Activity	Total Labour – all gardens (hours)	Average activity duration (mins)	Median activity duration (mins)	N =	% of total	(rank)
Harvesting	751.4	9	5	34	31%	1
Combined Irrigation	480.8	-	-	-	20%	(2)
(Mains)	*246.4*	*14*	*10*	*27*	*10%*	*2*
(Rainwater)	*214.9*	*20*	*12*	*19*	*9%*	*4*
(Bore/Grey)	*19.5*	*9*	*5*	*5*	*1%*	*13*
'Other'	223.3	28	5	14	9%	3
Livestock Care	189.3	18	10	18	8%	5
Weeding/Pruning	207.4	50	24	28	8%	6
Plant/Sowing	173.5	54	30	31	7%	7
Soil Prep/Mulch	166.7	70	45	27	7%	8
Building	147.9	123	60	18	6%	9
Sharing Produce	56.4	10	5	27	2%	10
Fertilizing	36.3	29	10	19	1%	11
Pest Control	24.4	50	20	9	1%	12
Total	2,457 hours					

[1] Not all the 34 gardens reported all the activities. The 'Other' category was used as a catch-all for activities which did not fall easily into the prescribed activities, for example, pollinating plants, repairing storm damage, working on aquaponics systems (including feeding fish), and seed saving.

During the initial online survey, respondents estimated their average weekly time spent on their food gardens (Pollard et al. 2018c). For each of the registered gardens in Phase 2, their reported average weekly time was compared with their initial survey estimation. The weekly time the EG gardeners estimated in the online survey was significantly higher (*Mdn* = 3.6 hours) than their reported average weekly hours spent (*Mdn* = 1.3 hours), (T = 22.5, $p = 0.001$, r = 0.8, N = 34). This could be due to an over-inclusion of time simply spent around the food garden when they answered the survey question, compared with the strictly activity-based monitoring they undertook while participating in Phase 2.

Interestingly, when the same comparison was made between the estimated average monthly costs from the initial survey and the average reported monthly costs, no significant difference was found. By considering each garden's reported setup cost, average monthly cost and average monthly retail value of the food produced, it was possible to calculate the length of time until each garden re-couped their costs and would theoretically "break even". Note that the setup costs for each garden were based on the estimated survey responses from the online survey. Table 4 displays the length

of time to break even for the EG gardens, while Figure 4 displays the setup, one-year and five-year net positions of the four garden size categories.

Table 4. Percentage distribution of the calculated time to break even.

Years to break even	No. of gardens	%
< 1 year	10	29
1.1 – 5 years	12	35
5.1 – 10 years	3	9
> 10 years	3	9
Never (costs more than retail value return)	6	18
Total:	34	100

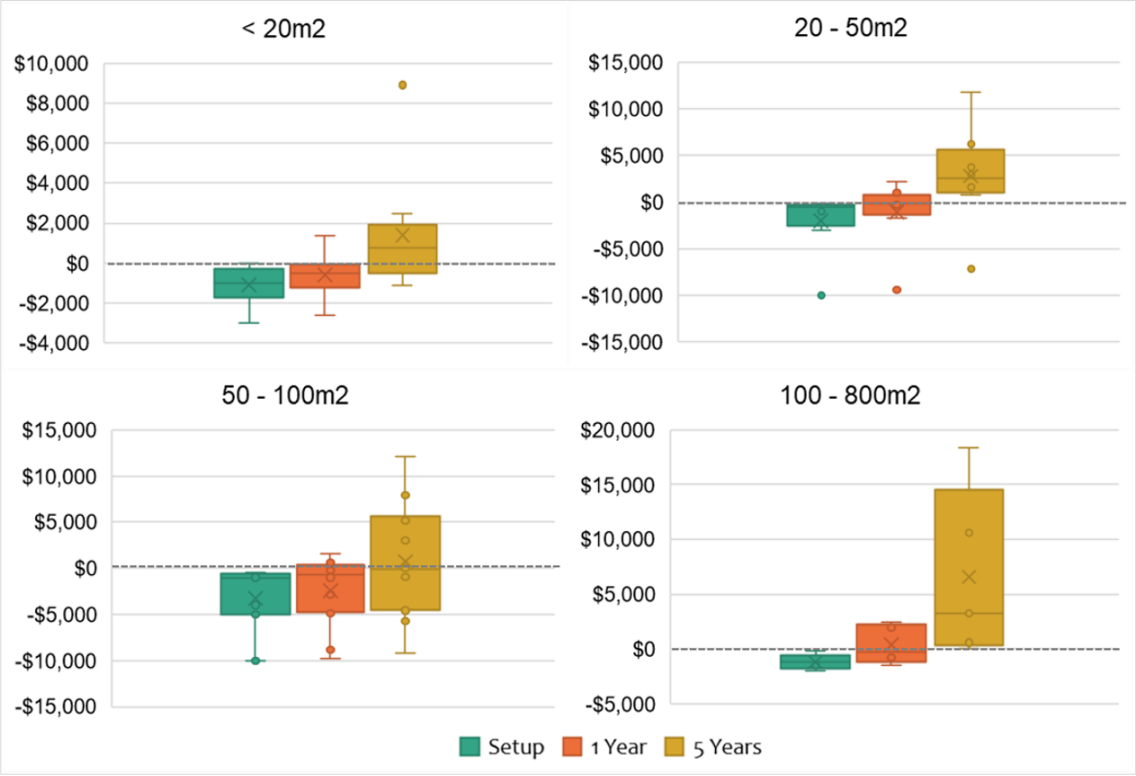

Figure 4. A progressive comparison of the setup, 1-year and 5-year net position of the different garden size categories.

On a more day-to-day level, the net returns (retail value minus costs including the cost of mains water) per hour invested by the EG participants ranged from -$3.73 to $87.76 with a median of $9.91 (N = 34). Figure 5 displays the full range of net returns and lines for comparison at $5 per hour and $30 per hour net returns. The Australian minimum wage line ($18.93/hr) has also been included.

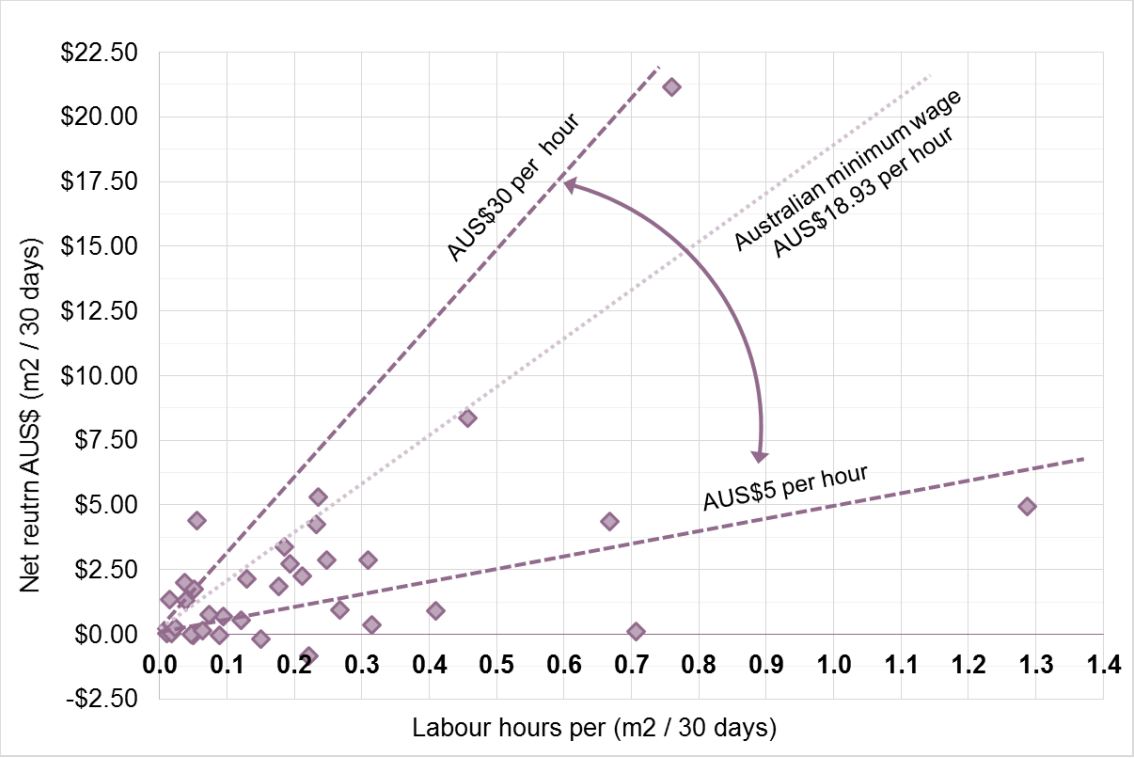

Figure 5. Net return (m^2/30 days) plotted against labour (m^2/30 days). Additional lines represent the lower (AUS$5/hour), Australian minimum wage (AUS$18.93) and upper (AUS$30/hour) bounds of the returns for labour.

The EG net return and the area under production can be compared with the net return and garden area per person as modelled by Ward et al. (2017) (Figure 6). Ward et al. (2017) used a two-stage linear programming model to optimise the theoretical net return of urban agriculture as based on home food gardens contributing to the dietary requirements of a household. It should be noted that the only inputs costed by Ward and Symons (25) was fertiliser and water, therefore their modelled results may be lower if taking all ongoing costs into account.

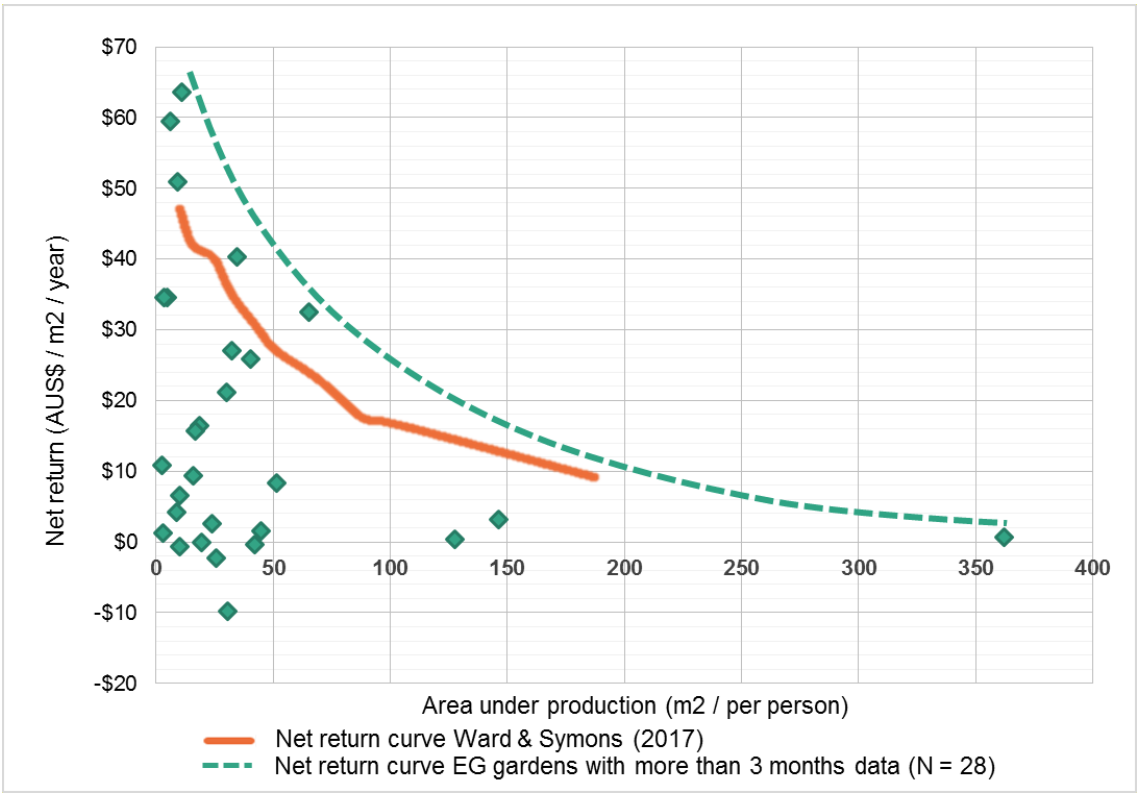

Figure 6. Comparison between the net return curve modelled by Ward & Symons (2017) and the upper net return envelope of those EG gardens with more than 3 months of data (N = 28).

Applying a theoretical wage rate to the time spent by the EG gardeners considerably alters the net position of the gardens. If gardens can only reliably deliver produce by valuing labour at less than a minimum wage, then this needs to be considered when evaluating their widespread contribution to future food security. Moreover, if gardening activities are to be scaled up to develop a new UA industry, then the ability of that industry to cover wage costs becomes a critical factor. Taking the minimum wage ($18.93/hr) and applying a casual wage rate with a loading of at least 25% makes the "benchmark" rate $AUS23.66 per hour. When applying either $18.93 or $23.66 per hour to the labour invested by the EG gardeners, the majority (82 – 85%) of gardens would be in a net loss position (Figure 7) on an ongoing basis, without even considering the setup cost of each garden.



Figure 7. The impact of applying a wage rate to invested labour and how this impacts the net position of the EG gardens.

Tech-crop Category Results

"Tech-crops" are a combination of the production method and the typical crop to create differentiated categories for growing areas. The approach was developed as a compromise between aggregating data at the level of garden area (not sufficiently detailed), versus differentiating data by individual crop (too impractical for participants). Of the 11 tech-crop categories involved in the EG project, five had sufficient numbers of data entries (>500) or sufficient numbers of individual areas (>10 across the 34 participating gardens) to form comparable samples. Supplementary Table 3 presents an overview of the five main tech-crops, while Supplementary Table 4 displays the time per activity per tech-crop category.

No significant difference was found among the tech-crops and their time spent on various activities. However, while looking deeper into how often our gardeners watered their garden areas, we did find an association between tech-crop category and the frequency of irrigation ($X^2_{12} = 155.76$, N = 1146, $p = 0.001$). The most dominant two frequencies were daily and then weekly for bed-veg/vegh/herb/other (46%; 31%) and for raised-veg/vegh/herb (50%; 40%). For chkn-egg the most dominant two frequencies were weekly and then daily (34%; 31%). In comparison, the dominant frequencies were

weekly and then every three weeks for bed-orch (40%; 33%) and for wick-veg-vegh/herb (43%; 30%) (Supplementary Figure 1).

There was also an association between season and the frequency of irrigation (X^2_{15} = 120.42, N = 1357, p = 0.001). The two most dominant irrigation frequencies were weekly and then daily in spring (50%; 35%) and in winter (51%; 26%), compared with daily and then weekly in summer (40%; 36%) and in autumn (45%; 33%).

Harvesting was another activity found to have an association with both tech-crop category (X^2_{20} = 33.60, N = 2646, p = 0.029) and season (X^2_{15} = 85.80, N = 2646, p = 0.001). There was also a difference when comparing the seasonal harvesting consistency (by number of harvesting events) of each tech-crop (X^2_{12} = 337.01, N = 4963, p = 0.001). Chkn-egg and raised-veg/vegh/herb/other areas appear to have the most consistent harvesting event frequency, although this did not translate directly to the quantities of food harvested each season from the tech-crop categories (Figure 8).

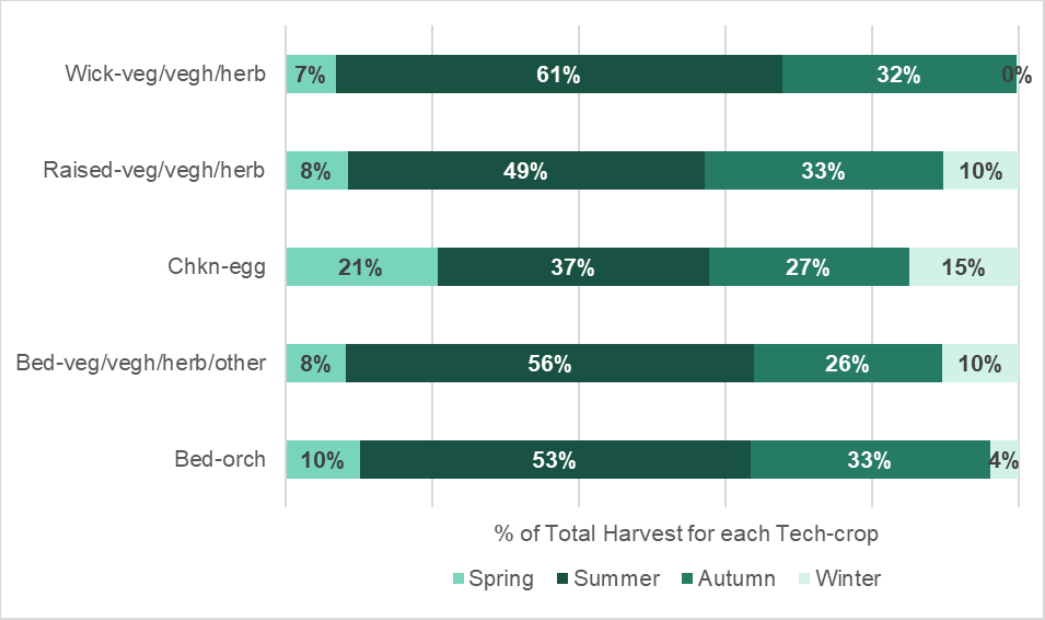

Figure 8. The seasonal proportions of the total harvest quantities from each of the tech-crop categories.

Having higher combinations of tech-crop areas also had associations with seasonal distribution of harvests (X^2_9 = 415.43, N = 4532, p = 0.001) and the diversity of crop categories (fruits, herbs, animal products and vegetables) (X^2_9 = 603.82, N = 4521, p = 0.001). Those gardens with four different tech-crop categories returned the most even-

proportioned seasonal spread of their harvests. And those gardens with three or four tech-crop categories appear to harvest the most even proportions of fruits, herbs, animal products and vegetables.

Table 5 displays the overall inputs and outputs of each of the main tech-crop categories. The tech-crop categories with the lowest median input requirements were bed-orch (labour), chkn-egg (total water) and bed-orch (costs). The highest median input requirements were wick-veg/vegh/herb (labour), bed-veg/vegh/herb/other (total water) and raised-veg/vegh/herb (costs). The tech-crop categories with the greatest median returns were raised-veg/vegh/herb/other (yield and retail value), while the lowest median returns were from bed-veg/vegh/herb/other (yield) and bed-orch (retail value).

Table 5. A comparison of the median input, output and WUE results of each of the five main tech-crop categories.

Tech-crop Category	bed-orch	bed-veg/vegh/herb/other	chkn-egg	raised-veg/vegh/herb	wick-veg/vegh/herb
Median labour (mins) /per m^2 / 30 days	4	9	8	16	18
Median total water (*W*) (L) / per m^2 / 30 days	51	99	9	93	95
Median irrigation (L) / per m^2 / 30 days	5	21	9	52	52
Median costs (+ mains water)/ per m^2 / 30 days	$0.02	$0.51	$0.77	$0.82	$0.60
Median yield (kg) / per m^2 / 30 days	0.19	0.17	0.25	0.39	0.27
Median retail value / per m^2 / 30 days	$0.85	$2.25	$2.19	$5.32	$3.48
Median net position / per m^2 / 30 days	$0.80	$1.61	$1.04	$2.18	$1.86
Median WUE_{gross} (kg/kL)	2.57	1.10	22.04	1.25	2.51
Median WUE_{nut} (kJ/kL)	4,347	1,813	123,121	1,607	2,134
Median WUE_{fin} ($/kL)	$10.42	$21.18	$192.35	$27.52	$38.16
Median size (m^2)	**10.0**	**15.0**	**10.0**	**12.0**	**5.0**

Despite the apparent difference in WUE values, the only statistically significant differences among the tech-crop categories were between chkn-egg and all the other four main tech-crop categories. There were differences in WUE_{gross} ($H(3) = 31.71$, $p = 0.001$, $\varepsilon^2 = 0.41$ (strong)), WUE_{nut} ($H(3) = 36.40$, $p = 0.001$, $\varepsilon^2 = 0.47$ (strong)) and WUE_{fin}

($H(3) = 34.69$, $p = 0.001$, $\varepsilon^2 = 0.45$ (strong)). Applying a Bonferroni correction found that chkn-egg areas had higher WUE_{gross} (*Mdn.* = 22.04kg/kL) than all the other tech-crop categories including bed-orch (*Mdn.* = 2.57kg/kL, $p = 0.001$), bed-veg (*Mdn.* = 1.10kg/kL, $p = 0.001$), raised-veg (*Mdn.* = 1.25kg/kL, $p = 0.001$) and wick-veg (*Mdn.* = 2.51kg/kL, $p = 0.004$). Chkn-egg areas also had higher WUE_{nut} (*Mdn.* = 123,121kJ/kL) than all the other areas, including bed-orch (*Mdn.* = 4,347kJ/kL, $p = 0.001$), bed-veg (*Mdn.* = 1,813kJ/kL, $p = 0.001$), raised-veg (*Mdn.* = 1,607kJ/kL, $p = 0.001$) and wick-veg (*Mdn.* = 2,134kJ/kL, $p = 0.004$). And chkn-egg areas had higher WUE_{fin} (*Mdn.* = $192.35/kL) than all of the areas: bed-orch (*Mdn.* = $10.42/kL, $p = 0.001$), bed-veg (*Mdn.* = $21.18/kL, $p = 0.001$), raised-veg (*Mdn.* = $27.52/kL, $p = 0.001$) and wick-veg (*Mdn.* = $38.16/kL, $p = 0.046$).

While the initial online survey did collect information on the setup costs of respondents' entire food gardens, it did not ask about the setup costs of individual growing areas. The setup costs for each tech-crop growing area were therefore calculated based on a combination of additional investigation into the typical retail costs of component parts, together with detailed costing obtained (in follow-up communications) from at least five participants per tech-crop category. Table 6 presents an overview of the various costs, value and an estimated time to break even for each main tech-crop. For a breakdown of the calculated setup cost details and assumptions, please refer to Supplementary Table 5. It should be noted that these costs include the retail costs of purchasing all the separate parts, and the figures could change with the use of second-hand or salvaged materials. Economies of scale have also not been fully considered, and the total setup costs of different areas may change according to total size and intensity of use. This is clearly an area that warrants future research.

Table 6. A comparison of the related costs and time required to break even for each of the five main tech-crop categories.

Tech-crop	Median setup cost ($ per m^2)	Median monthly costs (+ mains water) ($ per m^2)	Median monthly retail value ($ per m^2)	Min – Max (years)	"never" break even	Median time until break even (years)
Bed-orch	$22.73	$0.02	$0.85	0.42 – 62.1	3 (15%)	2.0
Bed-veg/vegh/herb/other	$18.91	$0.51	$2.25	0.04 – 11.70	4 (17%)	0.5
Chkn-egg	$121.46	$0.62	$1.87	0.39 – 38.00	3 (19%)	4.6
Raised-veg/vegh/herb	$106.09	$0.74	$5.27	0.91 – 7.90	5 (28%)	1.1
Wick-veg/vegh/herb	$222.82	$0.60	$3.48	0.76 – 58.00	1 (11%)	2.0

A series of Kruskal-Wallis tests were used to look for differences among the tech-crop categories. The median break even time for all the categories is less than five years, and although the initial Kruskal-Wallis test returned a significant result with differences among the tech-crop categories ($H(4) = 11.10$, $p = 0.025$, $\varepsilon^2 = 0.14$, $N = 80$), the follow on post hoc test using Dunn's test with the Bonferroni correction did not identify any significant pairwise comparisons.

There were, however, significant differences in the ongoing costs and the labour of the tech-crop categories, with bed-orch having much lower ongoing costs than the other four tech-crop categories. The differences in ongoing costs AUS$/m^2/30 days ($H(4) = 27.24$, $p = 0.001$, $\varepsilon^2 = 0.347$ (relatively strong)) with the Bonferroni correction showed significant differences specifically between bed-orch (*Mdn.* = $0.02) and the other four categories including bed-veg/vegh/herb (*Mdn.* = $0.51, $p = 0.004$), chkn-egg (*Mdn.* =$0.62, $p = 0.003$), raised-veg/vegh/herb (*Mdn.* = $0.74, $p = 0.001$) and wick-veg/vegh/herb (*Mdn.* = $0.60, $p = 0.004$). There were differences in labour hours/m^2/30 days ($H(4) = 21.53$, $p = 0.001$, $\varepsilon^2 = 0.271$ (relatively strong)), while the Bonferroni correction showed significant differences specifically between bed-orch (*Mdn.* = 4 mins) and the other four categories including, bed-veg/vegh/herb (*Mdn.* = 9 mins, $p = 0.018$), chkn-egg (*Mdn.* = 8 mins, $p = 0.021$), raised-veg/vegh/herb (*Mdn.* = 16 mins, $p = 0.001$) and wick-veg/vegh/herb (*Mdn.* = 18 mins, $p = 0.007$).

Both bed-orch and chkn-egg areas had lower irrigation requirements than the other three categories, and chkn-egg areas had lower total water (W) requirements. Differences in irrigation kL/ m^2/30 days (H(4) = 27.22, p = 0.001, ε^2 = 0.38 (strong)), while the Bonferroni correction showed significant differences specifically between chkn-egg (*Mdn.* = 0.009 kL) and three of the other tech-crop categories, including bed-veg/vegh/herb/other (*Mdn.* = 0.021 kL, p = 0.026), raised-veg/vegh/herb (*Mdn.* = 0.052 kL, p = 0.001) and wick-veg/vegh/herb (*Mdn.* = 0.052 kL, p = 0.013). There were also specific differences found between the irrigation of bed-orch areas (*Mdn.* = 0.005 kL) and the same three tech-crop categories including, bed-veg/vegh/herb/other (*Mdn.* = 0.021 kL, p = 0.045), raised-veg/vegh/herb (*Mdn.* = 0.052 kL, p = 0.002) and wick-veg/vegh/herb (*Mdn.* = 0.052 kL, p = 0.021). Differences in total water (*W*) kL/ m^2/30 days (H(4) = 42.63, p = 0.001, ε^2 = 0.58 (strong)), while the Bonferroni correction showed significant differences between chkn-egg (*Mdn.* = 0.009 kL) and bed-orch (*Mdn.* = 0.051 kL, p = 0.021), bed-veg/vegh/herb/other (*Mdn.* = 0.099 kL, p = 0.001), wick-veg/vegh/herb (*Mdn.* = 0.095 kL, p = 0.001), raised-veg/vegh/herb (*Mdn.* = 0.093 kL, p = 0.001).

The same three WUE equations were applied to the tech-crop categories (Figure 9) with WUE_{gross} compared against global average water footprint of related crops as reported by Mekonnen & Hoekstra (2011). Natural rainfall ("green water") was not accounted for in the EG calculation of the WUE values for chkn-egg areas. Comparison with the chicken egg average water footprint reported by Mekonnen & Hoekstra (2012) was attempted, however, their blue water figures also account for the irrigation applied to the chicken's feed. The WUE_{gross} results for chkn-egg areas in Figure 9 are instead compared to a range of estimated WUE_{gross} based on a brief review of online poultry keeping websites (assuming between 0.5 – 1L of irrigation per chicken per day, with average of 250 eggs per year at 60 grams per egg, which equates to a range of 15 – 30kg/kL). Wick-veg/vegh/herb presented the lowest variability in both WUE_{gross} and WUE_{nut}, while bed-orch presented the lowest variability in WUE_{fin}. Interestingly, bed-orch also presented reasonably strong WUE_{nut}. As this study did not consider the embodied water of the feed inputs, chkn-egg areas outcompete all other tech-crop categories in all WUE scores.

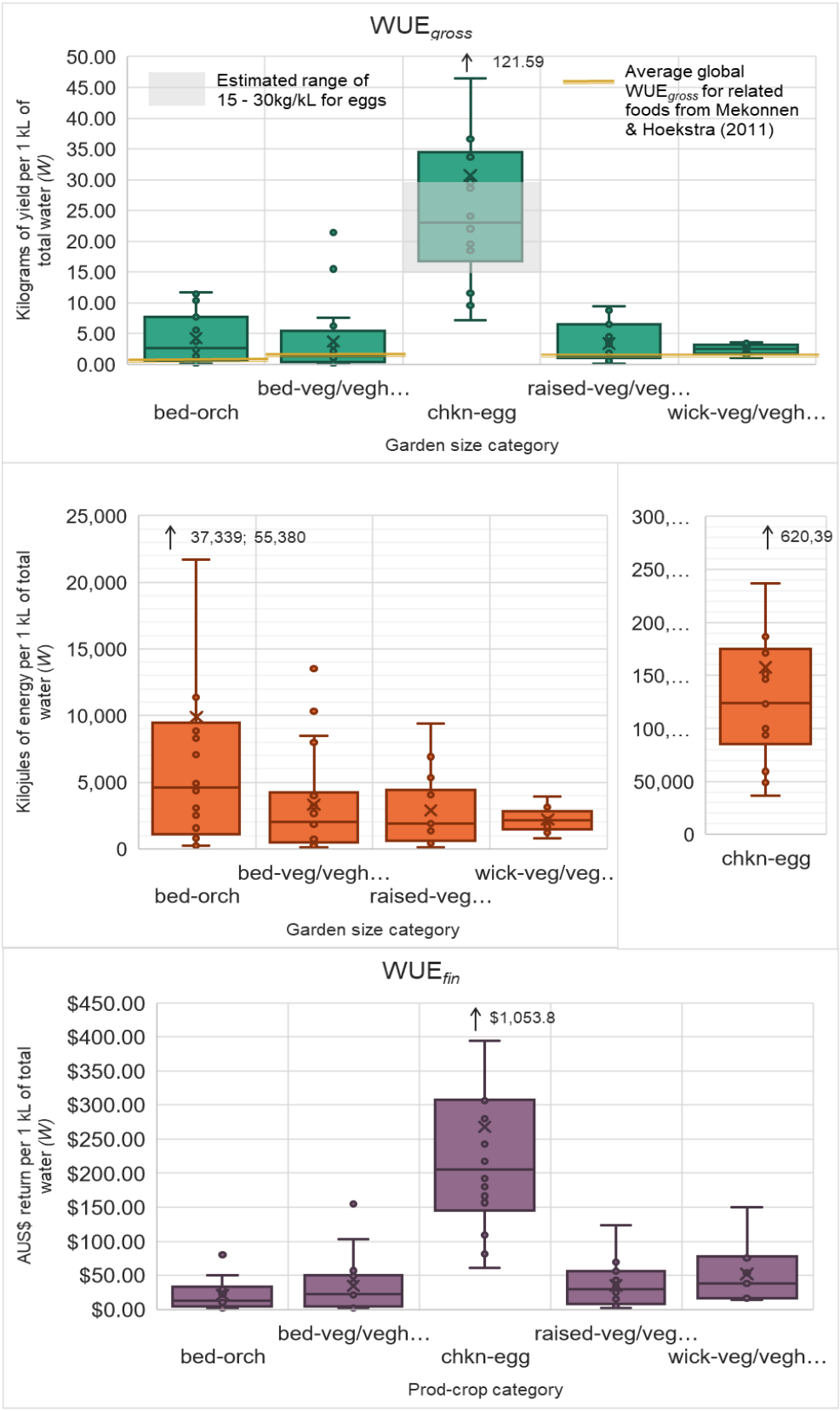

Figure 9. A comparison of the WUE_{gross}, WUE_{nut} and WUE_{fin} scores for each of the five main tech-crop categories. Outliers are identified by the arrows, and the chkn-egg WUE_{nut} scores required its own axis. The additional yellow lines on the WUE_{gross} chart represent comparative WUE values of related foods from Mekonnen & Hoekstra (2011). The grey band represents the

estimated WUE_{gross} range for chicken eggs (irrigation only) as based on a brief review of online poultry keeping websites.

Significant differences in the WUE of the main tech-crop categories were only found between chkn-egg areas and the other four tech-crop categories. There were differences in WUE_{gross} ($H(4)_4 = 31.71$, $p = 0.001$, $\varepsilon^2 = 0.41$ (strong)), WUE_{nut} ($H(4) = 36.40$, $p = 0.001$, $\varepsilon^2 = 0.47$ (strong)) and in in WUE_{fin} ($H(4) = 34.69$, $p = 0.001$, $\varepsilon^2 = 0.45$ (strong)). Applying the Bonferroni correction revealed that chkn-egg areas had higher WUE_{gross} (*Mdn.* = 22.04 kg/kL) than bed-orch (*Mdn.* = 2.57kg/kL, $p = 0.001$), bed-veg/vegh/herb/other (*Mdn.* = 1.10kg/kL, $p = 0.001$), wick-veg/vegh/herb (*Mdn.* = 2.51kg/kL, $p = 0.004$), raised-veg/vegh/herb (*Mdn.* = 1.25kg/kL, $p = 0.001$), higher WUE_{nut} (*Mdn.* = 123,121kJ/kL) than bed-orch (*Mdn.* = 4,347kJ/kL, $p = 0.001$), bed-veg/vegh/herb/other (*Mdn.* = 1,813kJ/kL, $p = 0.001$), wick-veg/vegh/herb (*Mdn.* = 2,134kJ/kL, $p = 0.004$), raised-veg/vegh/herb (*Mdn.* = 1,607kJ/kL, $p = 0.001$), and higher WUE_{fin} (*Mdn.* = $192.35/kL) than bed-orch (*Mdn.* = $10.42/kL, $p = 0.001$), bed-veg/vegh/herb/other (*Mdn.* = $21.18/kL, $p = 0.001$), wick-veg/vegh/herb (*Mdn.* = $38.16/kL, $p = 0.046$), raised-veg/vegh/herb (*Mdn.* = $27.52/kL, $p = 0.001$). No other statistical differences were found among the WUE of the different tech-crops.

Although the volume and types of food produced by the different tech-crop categories varied, no difference was found in their respective yields (kg/m^2/30 days). There was, however, a difference in the retail value of their yields ($H(4) = 13.04$, $p = 0.0011$, $\varepsilon^2 = 0.17$ (relatively strong)), while the Bonferroni correction found that bed-orch had a significantly lower retail value return (*Mdn.* = $0.80) than raised-veg/vegh/herb areas (*Mdn.* = $5.32, $p = 0.017$) and wick-veg/vegh/herb areas (*Mdn.* = $3.48, $p = 0.044$).

4. Discussion

Potential sustainable improvements in urban food production have been limited by the paucity of in-field data available, particularly on home food gardens, which are by far the most common form of UA practised in Australia (Wise 2014). This research contributes a range of input and output data, providing deeper insight into the productivity, resource efficiency and potential financial savings of home food gardens, using South Australia as a case study. The following discussion is split into three parts:

new findings on the state of existing urban food gardens (including productivity and resource efficiency); the potential of home food gardens to save money; and implications of these findings, including a new way for gardeners to select the most suitable garden setups for themselves.

New findings on the state of existing urban food gardens

Productivity

The EG gardens demonstrated a median yield of 0.21kg/m^2/30 days. A wide variety of crops and food products were produced from a range of different cultivation techniques. The tech-crop categories were developed as a simple way to identify different individual areas within the EG gardens. The categories support comparisons both within the gardens involved in an individual study and among various studies. Descriptions on garden types and growing areas until now have had no categorisation system to adequately define the diversity of existing urban food production. Each of the five main tech-crop categories present different input requirements and output returns, which in turn represent various trade-offs. The most productive categories (median kg/m^2/30 days) were raised-veg/vegh/herb, wick-veg/vegh/herb and chkn-egg. Raised-veg/vegh/herb and wick-veg/vegh/herb were also the two tech-crop categories with the best median retail value ($/m^2/30 days).

Resource efficiency

One surprising result was our gardeners' perceptions that they spent considerably more time tending their food gardens (according to the earlier survey results) than they reported when physically monitoring their time. This perception corresponds with findings by Wise (2014), who suggested that the estimated time from surveyed gardeners was considerably higher than the time suggested by professional gardeners. One possible reason for this difference is that time spent thinking, planning or deciding what to grow, may not have been fully accounted for in the EG measurements.

This finding is particularly interesting, as 'not having enough time' was both the top initial and the top ongoing challenge faced by the EG survey respondents (Pollard et al. 2018c). Bed-orch areas had the lowest median time requirements (4 mins/m^2/30 days), followed by chkn-egg areas (8 mins/m^2/30 days) and bed-veg/vegh/herb/other (9

mins/m²/30 days). Overall, the EG gardens had an average labour input of 14 mins/m²/30 days. This result is considerably lower than the reported average labour input of the 50 urban food gardens involved in the study by Codyre et al. (2014), which equated to 41 mins/m²/30 days. This variation could be partially due to the different durations of data collection, with some of EG gardens collecting data for more than a full year, compared with the 4-5 months of growing season suitable for data collection in the study by Codyre et al. (2014).

Much of the results presented here are scale-related. Lack of space does not automatically equal less productive potential. In fact, as the area under production increases, both the inputs and outputs per unit area decrease – i.e. the intensity of the gardening operation effectively decreases with scale. This finding corroborates the theoretical findings of a linear programming model by Ward et al. (2017). They found that per person, smaller gardens of between 10-20m² were optimal in their ability to produce both high-value and low-water use crops (Ward et al. 2017). These results also support approaches recommended by popular gardening literature which try to maximise the use of small spaces close to home, from compact crop varieties, intensive planting, vertical growing structures (Dorling Kindersley Australasia 2015), and in part validates the concept of 'concentric zoning' in permaculture literature (Morrow et al. 2006), whereby smaller intensive zones are flanked by larger and less intensive zones. Consideration of scale could also complement our findings on garden diversification. Some diversification of cultivation techniques may help to even out the input requirements and outputs of a single garden, provide more consistent year-round harvests and produce the most even (and diverse) combination of fruits, herbs, animal products and vegetables (if desired). These results support the concept of using a combination of smaller more intensive tech-crop areas, together with larger less intensive tech-crops areas with lower input requirements and concomitantly lower yields.

While water was the most challenging input to measure, the data presents some interesting results. Chkn-egg areas performed well in all the water-related metrics. Chkn-egg areas had the lowest median total water (W) requirements (10L/m²/30 days),

followed by bed-orch areas (51L/m²/30 days). The chkn-egg areas outcompeted all other tech-crop categories in all WUE scores. However, this study only considered the blue water footprint of chkn-egg areas (water provided for the chickens themselves) and did not measure the embodied water of the feed inputs – all the water required to grow the chicken feed (the 'green water footprint'). Mekonnen & Hoekstra (2012) reported global weighted average water footprint values for chicken eggs, divided into their green, blue and grey water footprint components. Thus, while the blue water footprint of the EG chkn-egg areas was quite low, this constitutes only 7% of the total egg water footprint (Mekonnon & Hoekstra 2012). Green water, such as the embodied water in the chicken feed, constitutes a further 79% of consumed water (Mekonnon & Hoekstra 2012). Further consideration of the water required to produce animal products such as chicken eggs is encouraged to ascertain overall sustainable impacts of keeping urban livestock. Another interesting finding was that wick-veg/vegh/herb areas did not outperform the other areas in terms of their irrigation or total water (*W*) requirements. Nor did wick-veg/vegh/herb areas present significantly better WUE scores. Indeed, the only metric where the wick-veg/vegh/herb areas out-performed the other categories was with their frequency of irrigation. The top irrigation frequencies for wick-veg/vegh/herb areas were "weekly" and then "every three weeks" (similarly to the bed-orch areas), whereas the other tech-crop categories had top irrigation frequencies of "daily" and then "weekly". This finding supports the only other published scientific research on wicking beds, by Semananda et al. (2016), who found wicking beds to be significantly more labour efficient than precision surface irrigation. While growing seedlings, the experimental wicking beds could go up to 4 weeks without irrigation, and with mature tomato plants could go 1-2 weeks without irrigation (Semananda et al. 2016).

Three of the four WUE equations proposed by Pollard et al. (2018b), were applied to EG results. The calculations provided understandable WUE values which are comparable with the values calculated for the study by Cleveland et al. (1985). The EG WUE results are also comparable to the global average water footprint values reported by Mekonnen & Hoekstra (2011). All the EG whole garden WUE scores either matched or surpassed the comparable scores of the two Cleveland gardens. Interestingly, while

the lower bounds of the EG tech-crop WUE scores matched the average global WUE_{gross} values of related crop types from Mekonnen & Hoekstra (2011), the majority of the tech-crop WUE upper bounds considerably higher. This suggests that the blue and green water footprint of home-produced food (not accounting for chkn-egg areas) can be comparable in water-efficiency to conventional farming.

The setup costs for the whole gardens differed greatly. Some differences were also found among the setup costs for the five main tech-crop categories. Bed-veg/vegh/herb/other has the lowest average setup cost (AUS$18.91/m^2/30 days), followed by bed-orch areas (AUS$22.73/m^2/30 days). Regarding the ongoing costs (including the cost of mains water), bed-orch areas again had the lowest median ongoing costs (AUS$0.02/m^2/30 days), followed by bed-veg/vegh/herb/other (AUS$0.51/m^2/30 days) and wick-veg/vegh/herb (AUS$0.60/ m^2/30 days). The cost of mains water was relatively small in the scheme of the total ongoing garden costs. While no water costs for rainwater, bore or grey water were recorded, it should be noted that these water sources are not free. The cost of the water applied to UA can be difficult to measure, as discussed in detail by (Pollard et al. 2018b), although mains water has a set cost, there remains disagreement over the levelized costs of alternative water sources. In general, the greater the irrigation and total water applied, the greater the yield and retail value returned from the garden. The corroboration of the EG WUE scores with the average global scores from Mekonnen & Hoekstra (2011) suggests that the EG participants were generally not substantially over- or under-watering.

South Australians reported that they are contributing similar proportions of home-grown food to their households as they did 40 years ago, with less than half of surveyed gardeners reporting more than a 5% offset to their fruit and vegetable costs. Therein lies a potential opportunity for new approaches or guidance to help increase the productivity and resource efficiency of home food gardens, and thus increase the contribution of home grown food.

Financial sustainability

"Breaking-even" and returns per hour

Wise (2014) hypothesised that approximately 16% of Australian food gardeners were producing yields worth more than $250 per year and thus achieving reasonable financial savings. A more recent study by Algert et al. (2016) investigated the potential cost savings and nutritional improvements of home grown food for low-income households. Algert et al. (2016) found that their eight home gardeners saved an average of USD$339 over the 4-month summer season. Comparing results is challenging as their gardeners' ongoing costs were estimated but not explicitly reported, nor was any labour data recorded. Codyre et al. (2014) reported an average cost of USD$10.82/kg, compared with the AUS$8.07/kg of the EG gardens. The EG garden data reveals slightly different results on how many gardeners save money. Even when taking the ongoing costs of each garden into account (but not the setup costs), 79% of the 34 EG gardens were calculated to save an excess of more than AUS$250 per year. The numbers were verified by the subset of long-term participants who had collected more than 240 days of data (N = 14), with 71% saving an excess of more than $250 per year. While this finding is quite positive for the large numbers of households looking to save money, the full cost of setting up a food garden has not yet been considered.

According to combined participant and author calculations of setup costs, 65% of the EG gardens would overcome both their setup and ongoing costs and break even within five or less years. Assuming garden assets are relatively long-lived (much longer than five years), after the setup costs have been paid off, it should be much easier to gain reasonable savings for a considerable time. This calculation was based on the average retail value of the food produced by the EG gardens, according to prices from two supermarket retailers. The time to break even would be considerably shortened if the calculation was instead based upon the retail value of certified organic produce (as sold at supermarkets). Indeed, for those households desiring to eat organic food but struggling to afford the higher prices, producing their own food as organically as possible is one way to access a cheaper alternative.

The median return rate on labour invested in the gardens was AUS$9.91 per hour. If gardening is taken as a simple hobby, with time spent as discretionary then the median

hourly return could be considered reasonable. Alternatively, for people who classify themselves as 'under employed' (defined as those those who wish to work more and are available to work more paid hours but who currently work less than 35 hours per week (Sabto 2013)), the labour data on the time requirements of different food garden related activities can help to account for the opportunity cost for someone considering whether to grow food as a form of alternative or supplementary employment. As of late 2018, South Australia had an unemployment rate of 5.2% and an underemployment rate of 9.6% (Australian Bureau of Statistics (ABS) 2018), thus this is clearly an area which would benefit from closer study.

Impact of applying a wage rate

Comparatively, applying a fixed wage rate (such as minimum wage) to the labour required to produce food, and adding it to the input costs, substantially alters the financial viability of most gardens. The cost of labour becomes a critical factor in considering the viability of potential commercial UA opportunities in any future urban vision. One of the early studies from 1980 by Stephens et al. found that even when the minimum wage of the time (USD$3.10/hr) was applied, the two gardens in their study both still returned net profits. It is interesting to note, however, that even then the labour costs consumed 19 – 51% of the retail value of the harvested crops and made up between 50 – 72% of the total garden costs, and the cost of urban water – for example – has risen considerably since 1980. In a more recent study, even before accounting for labour, the gardens involved in CoDyre et al.'s (2014) study were already calculated to run at a loss. The retail value of their harvests was based on the average price of 1kg of mixed vegetables with the same crop proportions as the average harvest. This resulted in an average value of USD$4.58/kg. Once the minimum wage rate of the area was applied, labour costs constituted 70% of the total costs and were more than double the other ongoing costs of the gardens [15].

The EG gardens median return rate of AUS$9.91 per hour is approximately half of the current Australian minimum wage for full time work (AUS$18.93 per hour) (Fair Work Ombudsman 2018). Even once the minimum wage rate was applied, 18% of the EG gardens produced enough food to effectively pay for their time at a legal wage rate. A

further 12% of the EG gardens were out of pocket, but by less than AUS$100, hence it could be argued that it would not take much of either an increase in productivity or a reduction in labour, to shift those gardens into a positive net position. It is important to note that these results are based on our monitoring and assessment of the relatively simple forms of urban food production involved in the EG project, i.e. methods commonly utilising hand tools and manual irrigation. A commercial urban food business would likely be organised differently and could potentially use a combination of labour-saving techniques and/or tools. Yet, the wage rate is likely become one of, if not the greatest, expense for commercial UA – even without considering the possibility of casual labour rates (an additional loading of 25% in Australia (Fair Work Ombudsman 2018)), or whether a UA business is able to sell their produce at retail or wholesale prices. This is an important consideration as new UA businesses are more likely to arise from serious home food gardens, rather than from any downscaling by commercial farmers.

Implications of the findings

To frame these results in a practical way the following section presents a series of recommendations, questions and comparative scenarios. To begin with, we recommend current and future food gardeners ask themselves two basic questions. The first is, "What do you want to get out of growing food?" This question relates to previously presented results from online survey questions asking people about their key motivations (Pollard et al. 2018a). The top five motivations of home gardeners were: 1) Producing fresh tasty produce, 2) Enjoyment, 3) Health reasons, 4) Natural connection and 5) To save money (Pollard et al. 2018a). Indeed, saving money was a motivation for 59% of the EG survey respondents. The second question is, "What are your biggest challenges or limitations?" This question relates to our previously presented challenges (Pollard et al. 2018c). The top six initial challenges for home gardeners when they first got into producing food were: 1) Lack of time, 2) Unsuitable conditions, 3) Lack of knowledge, 4) Lack of space, 5) Cost and 6) Water issues (Pollard et al. 2018c). Both the motivations and challenges of an individual gardener (or household) can be used to guide their choices in determining which tech-crop category (or combination of categories) would best suit them.

A similar perspective was investigated in a Tasmanian study by Kirkpatrick et al. (2018), who surveyed whether garden setups, gardener practices and gardener motivations were statistically related to each other. However, they found only two sets of "garden", "practice" and "motivation" to have positive associations (5). The approach presented here differs by our attempt to purposefully better relate gardener motivations and challenges to their garden setups from the outset (via the selection of suitable tech-crop categories). Figure 10 summarizes and ranks the input and output results of the five main tech-crop categories on a per square metre per 30-day basis.

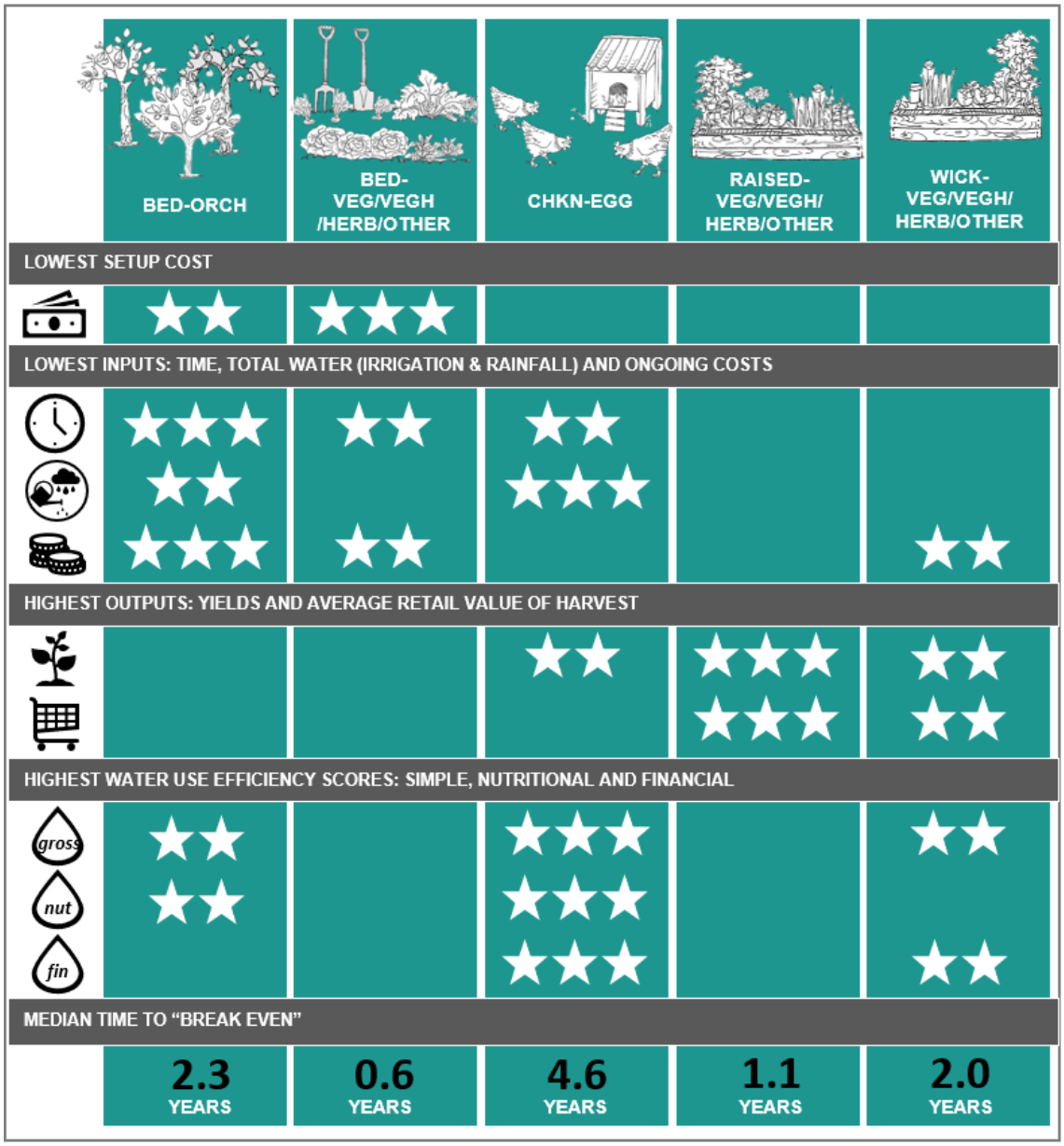

Figure 10. Comparison and ranking of the five main tech-crop categories by their inputs and outputs per square metre per 30 days. The number of stars represent the best performers in that category.

No single tech-crop category presents well across all inputs and outputs. There are different trade-offs for each. It is also important to note that the median size of each category is different – thus changing the results for entire larger tech-crop areas.

Recommendations to improve garden results

Gardener experience (as typically measured in years), is an interesting variable. Years of experience has been found to have a positive relationship with gardening efficiency (Codyre et al. 2014), and both a positive (Utzinger et al. 1978) and no measurable relationship, with garden productivity (Algert et al. 2016). We would argue that both knowledge and skills – and not just the number of years – are needed to apply and learn from food gardening experiences. Using the results from the EG project, we make a series of recommendations which may contribute to food gardener knowledge and thus potentially improve productivity and resource efficiency. This section includes insights into diversification, time saving and smart irrigation practices.

As discussed briefly above, some diversification of cultivation techniques may help to even out the input requirements and outputs of a single garden, provide more consistent year-round harvest and produce the most even (and diverse) combination of fruits, herbs, animal products and vegetables (if desired). In some cases, different techniques can co-exist in the same area (such as chickens under fruit trees). And yet, too many cultivation techniques and gardening approaches in a single garden was found to have a negative relationship with labour, yield and retail value per unit area. Potentially, utilising too many different techniques and approaches results in gardeners spreading themselves too thinly; at least some degree of specialisation is helpful. It has also been previously suggested that some diversification of food production can be more resilient overall in the face of natural disasters or climate-related challenges (Deppe 2010; Lin 2011; Reidsma et al. 2008). Diversification can also be implemented via crop type or crop variety choices. One way to both save additional money and to help extend the harvest period is to produce early- and/or late-season crops. Producing crops before or after their peak period, when they are at their most expensive to purchase from supermarkets can provide additional savings. For households who do not want to spend, or do not have the money to spend significant

amounts of money setting up new food garden areas, several ways to reduce the initial outlay were reported by the EG survey respondents. Materials or parts can be purchased second-hand, plants can be grown from seed instead of being bought as seedlings, and materials can be salvaged or found for free.

Food gardening does not appear to take as much time as was initially perceived by the participants. The median time spent per week by the EG gardeners was 1.3 hours, approximately one-third of the estimated time spent. But for gardeners who spend more time than this, or who consider themselves "time-poor", the two main activities to focus on for time-saving are harvesting (31% of all time spent) and irrigating (20% of all time spent). Developing quicker harvesting methods and planning different crops with rapid harvesting in mind can help to reduce labour requirements. Although bed-orch areas require the lowest amount of ongoing labour, newly planted trees do require time to establish their roots before any reasonable harvest can be expected.

In addition to harvesting, irrigation is a core component of food production. Irrigation took 20% of the total labour of the EG gardens. This time did not account for the durations that irrigation systems were running, only physical time spent. Half of that time (246.4 hours) was spent irrigating with mains water. If the minimum wage of AUS$18.93 was applied (as it would be in a commercial situation), 246.4 hours represents $4,664.45 worth of labour being spent irrigating with mains water. With the total reported volume of mains irrigation being 464kL, the labour cost of that water is on average, AUS$9.40 per kL. Therefore, although the cost of mains water was (for the most part) low relative to the retail value of the produce, the average cost of mains water (already considerably higher than that paid by commercial farmers in South Australia (Australian Bureau of Statistics (ABS) 2016)) becomes multiplied by four once the cost of labour for irrigation is taken into account. Alternative water sources such as rainwater, bore or greywater may have lower levelized costs than mains water (Pollard et al. 2018b), but are subject to the same potential labour costs for irrigation. Implementing automatic irrigation systems can significantly reduce the amount of time spent irrigating, and thus also reduce potential labour costs.

We recommend all gardeners use water flow meters to increase their understanding of the volumes of water being applied to different areas of their gardens. And finally, we encourage those interested in making the most of their irrigation, particularly collected rainwater, to learn about their soil's capacity to store water (Berardy et al. 2017; Stirzaker 2010). For gardeners wanting to reduce the worry or inconvenience of managing a consistent watering regime, they can use either an automatic irrigation system (preferably one with flow meters built-in), install wicking beds or plant in-ground fruit trees, both of which are tech-crop categories that require less frequent watering. If WUE does become a key metric for measuring the success of UA – this will help shift the focus from pure productivity, to a more inherently sustainable focus of food, water and land.

Limitations

This project required considerable supporting infrastructure, particularly the online web interface and the development, customisation and posting of the data collection toolkits. If additional resources were available, we would recommend stronger engagement of community gardeners in the garden data collection phase, targeted data collection on the less common tech-crop categories (such as aquaponics), and specific reporting of setup costs for all individual areas. The large supporting project infrastructure also required considerable time to set up. As a result, the sample size of 34 gardeners is relatively small. However, the collection of data from all the individual garden areas, resulted in an effective sample size of 92 garden areas.

Future Directions

We strongly encourage further research into the productivity, resource efficiency and financial viability of urban food gardens, including the prospects of households saving money by growing food (and implications for food security if they do not). Continued collection of input and output data will further contribute to the development of consistent and comparable baseline data on whole gardens and the tech-crop categories. Investigation into the less common tech-crops, for example, the keeping of bees, producing food in pots and planters, vertical gardens and assessment of multiple-purpose or layered garden areas is also recommended – with a mind to embrace, rather

than over-simplify, the rich diversity of existing urban food production. Appropriate use of scale and diversification may have implications for planning and optimising effective UA design. The water-use and water-use efficiency of urban food gardens remain a key area of interest. The development of simple technology, such as flexible water meters suitable for different water sources (with varying flow rates and pressures) and more automatic irrigation systems with built-in flow meters, would help increase the understanding and awareness of water use in urban food gardens.

5. Conclusion

This research provides a detailed insight into the form and function of existing home food gardens. The successful collection of a wide variety of input and output data demonstrates that a citizen science approach is an effective way to undertake in-depth UA research on existing urban food gardens in general, and home food gardens in particular. The overall contribution of this research is threefold. Firstly, this research contributes a rigorous methodology for collecting data on existing urban food gardens through the application of citizen science, replicable measurement methods, consistent units of comparable values, garden area categories and WUE efficiency equations. Three of the WUE efficiency equations proposed by Pollard et al. (2018b) were successfully applied to the EG results, showing for the first time that the water efficiency of home-produced food is comparable to conventional farming. The different WUE scores provide a simple way to compare different food gardens and different tech-crop categories, and are the first WUE data collected and reported on existing home food gardens.

Secondly, the in-depth range of key input and output data reported in this paper form the beginnings of a baseline dataset, which will be available open-source for external use, analysis, comparisons and theoretical modelling. The most successful tech-crop categories were: Chicken-eggs for all WUE, In-ground fruit tree orchards for the lowest time requirements and ongoing costs and Raised mixed vegetable and herb beds for the highest productivity and retail value returns. Smaller food gardens were found to be more intensive with higher input requirements and higher output returns than larger food gardens per unit area.

And finally, the analysis and comparisons presented in this paper provide detailed insights and practical implications for urban food gardeners, local councils and those interested in the larger future potential of UA within a vision of urban sustainability. Urban food gardeners can match their individual motivations and challenges to the trade-offs of different tech-crop (garden area) categories and identify the most suitable for themselves. Of the gardens involved in the EG project, 65% were set to break even in five or less years and save money, and after applying a minimum wage almost one in five gardens are financially viable. With this new dataset, work can now begin to investigate ways in which to nurture, encourage and optimise gardens, to potentially increase their contribution of urban food production in the future.

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7 Discussion and Conclusions



It is anticipated that in the future, urban agriculture (UA) will contribute in a variety of ways to society's attempts to create more environmentally sustainable cities and urban areas. The potential contributions of UA include improving urban food security via the production of fresh local food, strengthening urban resilience against food shortages, helping to conserve resources via recycling of urban wastes, more efficient resource use, acting as a mechanism to re-connect people with their food systems, and helping households save money. It has been unclear, however, how much food UA will contribute to our future cities and whether this will come as a net savings or a net cost. If UA is to become a reliable part of future food plans, then the full costs, resource requirements and the practical effort in its production must be taken into consideration, before scaling it up and out. Entwined with these considerations of measurements and resources is the underlying influence of how those growing food *feel* about what they do and why they do it, and the connections they have with others. We need to better understand all the different kinds of worth of UA.

Overview of research aim and objectives

This research investigated the productivity, resource efficiency and social value of urban food gardens in South Australia. The four key objectives of this research and the chapters in which they were met are listed below:

1. ***Assess the scope of previous urban agriculture measurement research in developed countries and identify gaps in data and measurement procedures.***

Previous UA yield, measurement, water use and WUE research were critically reviewed, with gaps in data collection and in measurement procedures identified throughout chapters 2, 3 and 4.

2. ***Develop and implement a novel approach to enable widespread measurement of urban agriculture input and yield data on existing urban food gardens.***

   A state-wide citizen science project, Edible Gardens (EG) was developed as a novel approach to enable widespread measurement of inputs (time on UA related activities, water use from various sources and irrigation methods, and all costs) and outputs (yield per crop, current retail value, estimated nutritional value and the tracking of any food sharing) on existing urban food gardens. The project was described in throughout chapters 2, 3, 4, 5, and 6, with chapter 6 presenting the bulk of the in-field collected data.

3. ***Clean, manage and analyse collected data from both Phase 1 (the online survey) and 2 (the garden data collection) to gain an in-depth understanding of existing urban food gardens in South Australia.***

   Data collected from the project was cleaned, analysed and comprehensively examined to develop insights into the state of existing urban food gardens in South Australia. Results were reported in chapters 3, 4, 5, 6, again with chapter 6 presenting the bulk of the in-field collection data.

4. ***Respect and acknowledge the reciprocal relationship with the 'citizen scientists' (project participants) who contributed data.***

   The reciprocal relationship with the citizen scientists who engaged with the EG project was respected and acknowledged throughout this research, including in chapters 2, 3, 4, 5, 6 and 7. Examples of the interactive project website and of the reports given to participants are presented in Appendix A.

The data collected as part of the EG project provides baseline data on the state of existing urban food gardens. The EG project represents a comprehensive method for

obtaining consistent and comparable data to enable assessment of the potential contribution of UA to improve our collective vision of a sustainable future.

Critical review of major findings

The contribution of the research design

This research project saw the successful development and demonstration of several practical methods and equations to support the collection and comparison of robust input and output data from UA. The practical elements promote a deeper understanding of the productivity, resource efficiency and social value of existing UA, particularly home food gardens. The citizen science approach successfully enabled the EG project to engage a cohort of urban food gardeners to collect input and output data on a wide range of UA activities over an extended period of time. The state-wide project had a sophisticated web-interface for promotion, registration, data entry, data management and interactive data displays. Promotion of the project was achieved largely through existing social networks and social media. Overall there were 402 survey respondents and 34 gardens monitored consistently, containing 92 individual garden areas.

Most of the challenges inherent in conducting UA research on existing urban food gardens (namely, diversity, geographic spread of study sites and locations on private property) were overcome. The EG project was able to bypass the challenge of collecting data from widely dispersed gardens positioned on private property. Collecting data on the broad diversity of cultivation techniques, crop choices, water sources and irrigation methods present in urban food gardens was a challenge which required the development of specialised research methods.

A series of methods were proposed and developed during this research, including garden area categorisation, flexible water-use measurement tools, and different ways to measure, calculate and present the input and output results of whole food gardens, and their separate garden areas. Development of the "tech-crop" categories helped to account for the diversity of cultivation techniques and the typical crops of individual garden areas. Testing and demonstrating the use of a combination of water meters

helped account for the variety of water source and irrigation method combinations. Introducing "time" into the calculation and presentation of the input and output results, for example, yield as 0.25 kg per m^2 per 30 days, supports consistent comparison both within individual UA studies and among UA research from around the world.

The reciprocal relationship with the citizen scientists involved in the garden data collection was highly valued. Participants involved in the garden data collection were supported by the project's online interface and received personalised reports on their garden results. Considerable time, effort and funds went into the design and creation of both of these supporting resources. The web-interface was described in detail in chapter 2, which also briefly mentions the participant reports. The reports were created in MS Excel and drew data from several spreadsheet files containing survey data, collected garden data, retail value data and nutritional content data. The report format was designed to be informative, engaging and visually pleasing.

The reports thanked each contributor for their dedication and presented the total input and output results from the EG project. Additionally, participant's individual results from the factor analysis of deeper values from the online survey were presented (as discussed in chapter 5), along with an explanation of those results. An overall summary of their food garden results were outlined, including their total inputs (water, labour and costs) and their total yield complete with information on average supermarket retail value, approximate organic retail value and inherent energy and protein content of the food produced. All the results were presented as total values and as values per square metre. The reports also contained graphs of the participant's time spent per activity and how much (if any) and what kinds of food they shared with others. Inputs and yield results for each of their growing areas were also presented (up to a maximum of four growing areas per garden for practical reasons). Each report was presented via email. Anecdotally, feedback from participants about their reports was highly positive. An example of a report is presented in Appendix A. The final reports were important, as acknowledgment of the reciprocal relationship with the citizen

scientists involved in your research is a key component of the citizen science ethic (Droege 2007; Roetman 2013; Roy 2012).

Future research into UA can apply the approaches, methods, recommendations and equations presented throughout this thesis. The findings of this research will support the continuation and expansion of practical UA research.

New findings on the state of existing urban food gardens

Social value, health & wellbeing

Regardless of their garden's productivity, people strongly believe they gain other benefits or values from producing some of their own food. While focussing on the more social aspects of UA, in addition to the potential health and happiness benefits, some differences were identified between home and community gardeners. The key difference overall was social connection. Community gardeners were more strongly motivated by social connection with people outside of their own households. In contrast, home gardeners did not appear to actively value or desire inter-household social connection, although this did not mean that they did not value or participate in other documented avenues of social connection, such as via social learning sources or by sharing food with others. Further, home food gardens can support intra-household social connection, such as interactions between parents and children.

Growing and producing food is at heart a "hands on" experience. Carolan (2016) discusses the importance of "sticky knowledge structures" – experiences and moments that are felt strongly enough to "stick" with people and influence or change the ways they feel, know and do things. The connections found linking the EG home gardeners with others included learning from social sources (typically face-to-face interactions), some sharing of the actual growing and producing with others in the same household and sharing harvested food with others. Although home food gardeners were described in chapter 5 as typically having "subtle sociability", these connections still suggest similar "sticky knowledge structures" at work in South Australia.

Carolan (2016) further advocates the importance of urban food growers coming together to share experiences and knowledge and thus "co-create" and "co-

experiment" together. Such connections and experiences can help amplify the influence and uptake of change and knowledge (Carolan 2016). Across South Australia there exist a wide range of channels which facilitate the sharing, swapping, selling and gifting of excess fresh food. A fine example of this "co-experimentation" is the Grow Free network. "Grow Free" is a network of physical (and typically colourful) carts placed in public places where people can leave and take seedlings, excess fresh produce and seeds (Barker 2018). The ethos of the carts is that nothing can be sold or bartered – things are just freely given and freely taken. But what began as a few carts in one suburb, has become a large-scale network of more than 150 registered carts in South Australia alone (with more beyond) – all dedicated to making food locally grown, organic and free (Barker 2018).

More personal motivations and perceived benefits of the EG gardeners included improved health from consumption and growing of fresh, healthy and (mostly) low chemical food, the tranquillity and timeout factor addressed in chapter 5, and the influence of enjoyment as one of the top three motivations of both home and community gardeners. No record was collected on whether the garden data collection participants actually consumed the food they produced, or whether participation in the Edible Gardens project helped increase fresh food intakes. However, it has been previously documented that participation in home (Algert et al. 2016; Kortright et al. 2011) and community gardening (Alaimo et al. 2008; Carney et al. 2012) can encourage the consumption of increased quantities and diversities of fresh foods. Interestingly, exercise did not appear to be a strong motivator for the EG survey respondents, with only seven people mentioning any form of exercise or fitness in their responses. Looking further into the potential energy expenditure of urban food production, and gardening in general, Ainsworth et al.'s (2000) Compendium of Physical Activities, gave "gardening general" a metabolic equivalent (MET) intensity score of 4.0, with "picking fruits/vegetables, moderate effort" receiving an intensity score of 3.0 METs (3 – 6 METs is classified as moderate intensity). By comparison, typical gym related activities have higher MET intensity scores, for example, 5.5 METs for "health club exercise, general", 7.0 METs for "stationary bicycling, general", "rowing, moderate

effort" and "jogging, general", and 8.0 METs for "circuit training, general" (> 6 METs is classified as vigorous intensity).

MET intensity scores can be used to calculate energy expenditure in kilocalories (which can in-turn be converted into kilojoules), by multiplying METS by an individual's weight in kilograms and then by the number of hours the activity was undertaken. Using the average weight of an Australian woman (71.8 kg) and man (87 kg) (Australian Bureau of Statistics (ABS) 2018), we can compare the energy expenditures of gardening with gym-related exercise. It appears that while "gardening, general" has a calculated energy expenditure of 1,201.6 kilojoules (or 287.2 kilocalories) per hour for women and 1,456.0 kilojoules (or 348.0 kilocalories) per hour for men, using the intensity score of 7.0 METs attributed to stationary bicycling, rowing and jogging reveals a higher energy expenditure of 2,102.9 kilojoules (or 502.6 kilocalories) per hour for women and 2,548.0 kilojoules (or 609 kilocalories) per hour for men. Thus, purely in terms of energy expenditure, people would need to spend roughly twice the amount of time gardening, as they would at the gym to use the same amount of metabolic energy. Nethertheless, the combined results from this research on health, wellbeing, social connection and happiness support the premise that engagement in home or community food gardening can provide a preventative or supportive role for gardener health and wellbeing, regardless of whether it is a conscious motivation for participation.

At the individual or household level there are personal experiences relating to producing food which contribute to a gardener's "self" (Figure 1). In this research, the "self" is comprised of a gardener's gardening experience, their use of learning sources (social and otherwise) and their connection or influence from "tradition". Based on the EG survey, "tradition" references connection to family, to people's childhood experiences, to cultural connection and memories of the past. Outside of this, each "self" produces food in a particular place or space to which they have a connection. Gardens are not theoretical constructs, they are site-specific creations grounded in physical locations. Each garden's place not only shapes physical aspects of a person's food production, but also engenders deeper emotional, sensory and other non-rational

connections (Delind 2006; Tuner 2011). "Self" and "place" make up the two core layers which are valuable to understanding each individual gardening situation. In turn both these layers influence each gardener's motivations and challenges.



Figure 1. Conceptual model of the layers involved in personal gardening situations.

Regarding the outcomes of UA, both the practical and value-based outcomes of producing food in urban areas can cycle back to bolster (or reduce) different aspects of the personal gardening situation (Figure 2).

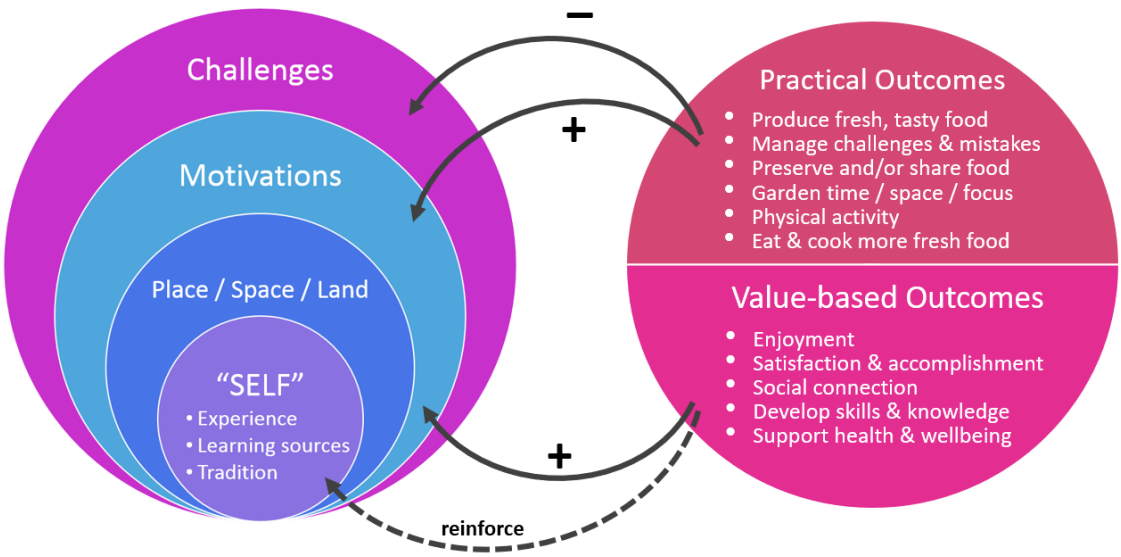

Figure 2. Conceptual model of influence of practical and value-based outcomes from urban food production on the personal gardening situation.

Productivity

The EG gardens produced a wide variety of fruits, herbs, vegetables and animal products from almost a dozen different cultivation techniques. While the median yield from the EG gardens was 0.21kg per square metre per 30 days, there was also tremendous variability among the gardens. Thus, while some gardens do exceedingly well, overall there is still considerable room for improvement. Existing urban food gardens are complex combinations of cultivation techniques, gardening approaches, crop choices, water sources, irrigations methods, motivations, challenges and outcomes. It is not easy, but it is necessary to consider food gardens comprehensively.

New urban food gardeners often have a more challenging time producing food than experienced gardeners. Figure 3 compares the individual gardening situation of new gardeners with experienced gardeners. The key differences involve the inner "self" layer and the outer "challenges" layer. New gardeners have less "self" to draw upon when trying to produce food. They have little (or no) food gardening experience and do not use as many different learning sources. Their sense of, or influence from, tradition may be higher or lower. However, tradition does appear more highly on their list of top motivations than it does for experienced gardeners. New gardeners also face more challenges, including a "lack of knowledge". In comparison, experienced gardeners have more "self" to draw upon, have a higher desire for convenience in their food production and face fewer (and different) challenges.

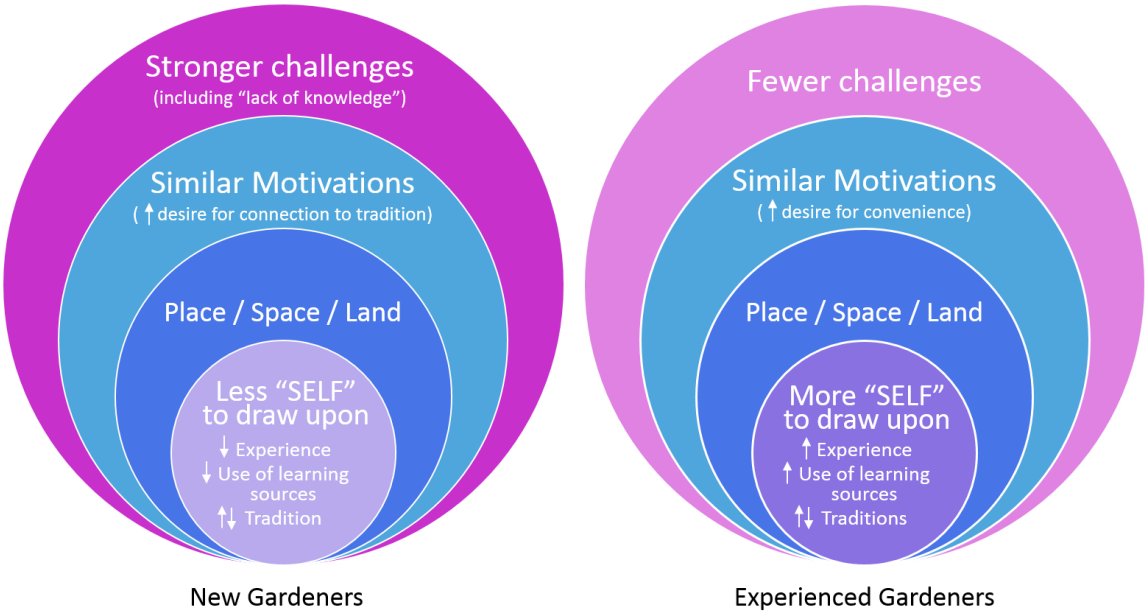

Figure 3. A comparison of the individual gardening situation (self, place, motivations and challenges) of new and more experienced gardeners.

The household proportions of food contributed by urban food gardens does not appear to have changed dramatically in South South Australia in over 30 years. This observation may signify a need to help households produce greater quantities of fresh food for themselves and also for others. The most productive tech-crop categories of the EG project were raised-veg/vegh/herb, wick-veg/vegh/herb and chkn-egg in median kilograms per square metre per 30 days. Raised-veg/vegh/herb and wick-veg/vegh/herb were also the two tech-crop categories with the best median retail value return per square metre per 30 days.

It is recommended that future UA research develop a simple way to estimate or measure food gardening skill with a clearer focus on ability rather than years of experience. While Utzinger et al. (1978) suggested a positive relationship between years of experience and productivity and Codyre et al. (2014) calculated a positive relationship between experience and gardening efficiency, Algert et al. (2016) found no relationship related to gardening experience. Although 7% of the EG survey respondents had less than one year of food gardening experience, none of those respondents participated in the garden data collection. Of the consistent garden data collection participants, most had more than 11 years of experience. Therefore, while

some differences were found in relation to food gardening experience, it is not clear how important years of food gardening experience are to the development of food gardening skill.

Resource efficiency

The EG project focussed on three key inputs: labour, water and financial investment. Each of these inputs can be limiting factors of urban food production, particularly if they are limited in supply or used inefficiently.

Lack of time was reported as both the top initial and top ongoing challenge in the EG online survey, with a median estimated weekly time input of 3.6 hours. The citizen scientists involved in the garden data collection then measured and recorded time spent on all food garden-related activities and reported a median weekly time input of 1.3 hours. Thus, it seems that seeing urban food production as a time-sink is a common misperception. This misperception represents an opportunity to educate people on how little time producing food can take, particularly for those who abstain from producing food purely because they consider themselves as "time poor". It is important to note that time recorded by the EG garden data collection participants did not account for time spent thinking about, planning or designing food gardens, but time expended on these activities is likely to be minimal over the life of the garden.

Water use has been identified as the most overlooked and understudied aspect of urban food production (Mok et al. 2014; Pollard et al. 2018; Ward et al. 2014; Wortman et al. 2013). The diverse combinations of water sources and irrigation techniques potentially present even within a single food garden remain challenging to measure robustly. With only one water meter provided per land/house block by the State of South Australia (typical for all of Australia), people have no simple way to separate their in-house water use from their outside water use, let alone have any way to separate their food garden water consumption from the rest of their garden and other outside uses. Initial confusion about estimating typical volumes of water applied to food gardens in the survey also suggests a general lack of awareness and understanding of water use in UA.

The EG garden data collection participants were provided with a customised combination of water meters to measure their food garden's water use. The combined use of the two types of water meters enabled data collection from most gardens, the majority of which utilised multiple water sources and multiple irrigation methods. Other possible methods for measuring water use were proposed in chapter 3, two of which do not require the use of water meters. Routine collection of four key metrics by future UA research: area under production, duration of study, overall water (rainfall and irrigation combined, and if possible, an estimate of change in soil moisture conditions) and yield per crop category is strongly recommended. This routine would enable post-process calculation by others of at least the basic WUE_{gross} of the food gardens involved and would support more meaningful comparison of different studies and represent a major improvement of the field of UA research. Until the research presented in this thesis, no scientifically-recorded data on the WUE of existing UA gardens was found (Pollard et al. 2018b).

To briefly re-interate from chapter 3, WUE_{gross} relates total gross yield to total water use (total water is the combination of applied irrigation and rainfall) (Pollard et al. 2018b). WUE_{nut} incorporates a nutrional unit (such as energy content in kilojules) per kilogram of produce, and WUE_{fin} incorporates the retail value of the total yield (Pollard et al. 2018).

The EG gardens median WUE_{gross} score of 2.22kg/kL falls within the range of global average WUE_{gross} scores for comparable commercial crops (Between 1.14 kg/kL and 4.22 kg/kL) as based on water footprint results reported by Mekonnen & Hoekstra (2011). Mekonnen & Hoekstra (2011) reported waterfootprint results for separate crop categories, whereas the EG project reports combined crop WUE scores. Therefore, Mekonnen & Hoekstra's (2011) WUE_{gross} scores above were calculated as averages from related crop categories including, 'vegetables', 'roots and tubers', and 'fruits'. Overall however, there was considerable variability in all the WUE results of the individual gardens. The WUE_{gross} scores ranged from a low of 0.14 kg/kL to a high of 10.69 kg/kL. The WUE_{nut} scores ranged from a low of 132 kJ/kL to a high of 12,486 kJ/kL (*Mdn*. of 3,634 kJ/kL), while the WUE_{fin} scores ranged from a low of AUS$1.85/kL to a high of

AUS$77.48/kL (*Mdn.* of AUS$21.88/kL). The WUE_{fin} scores are particularly interesting as they can be compared with the per kilolitre cost of the water itself – which if using mains water in South Australia is currently valued between AUS$2.32/kL - $3.58/kL (SA Water 2016). The broad variability of all the WUE scores again emphasise that there is room for improvement and optimisation.

Regarding costs, the setup costs varied considerably among the gardens, with some gardeners reporting spending no money, while others spent more than $10,000 for an entirely new setup of garden areas, fencing, irrigation systems and rainwater tanks. Average setup costs for each of the five main tech-crop categories were calculated and presented in chapter 6. The ongoing costs (including the cost of mains water) for different tech-crop categories and whole gardens, were found to be relatively low. In the discussion of chapter 4, the possibility was raised as to whether the setup or ongoing costs of urban food gardens were too great a barrier for low-income households. For households with little disposable income, or those most keen to save money, ways to help reduce these costs such as, salvaging parts or materials, purchasing things second-hand and growing plants from seeds, were discussed earlier in chapter 6.

Financial Findings

The majority of the EG survey respondents both desired, and believed, that they were managing to save money by growing some of their own food. Of those for whom producing food is simply an enjoyable hobby, the median return per hour invested was AUS$9.91 – approximately half of the Australian minimum wage for full time work (set at AUS$18.93 per hour) (Fair Work Ombudsman 2018). Even when considering ongoing costs, a high percentage of the EG gardens (79%) were calculated to save more than AUS$250 per year. This is considerably higher than the 16% of Australian food gardens which Wise (2014) hypothesised were succeeding in achieving similar financial savings. Of the 34 home gardens which collected consistent input and output data on their own gardens, the majority were calculated to overcome both their setup and ongoing costs and break even in five or less years.

Applying a wage rate to the time spent altered the net financial results. Even before applying a wage rate, the gardens involved in the empirical study by Codyre et al. (2014) were running at a loss due to their ongoing costs. In that study, once a wage rate was applied, labour became the single largest cost (70%) of their food gardens. The results from the EG gardens differ. Although the majority of the EG survey respondents desired to save money, for the most part by spending less on purchasing fresh produce, some of the garden data participants produced enough food to effectively pay for their time at a legal wage rate. Once the Australian minimum wage of AUS$18.93/ hour was applied to all labour, 18% of the EG gardens still finished in a positive net financial position. This result is both positive and surprising (as previous research and anecdotal advice did not support such results). Although these results are based on the monitoring and assessment of relatively simple forms of urban food production (typically using hand tools and manual irrigation methods), this still has implications for future commercial UA businesses, in which labour is likely to be one of, if not the greatest expense. These results suggest that, if the growing area was set up and managed efficiently, it would be possible for urban growers to make at least a minimum wage from UA.

Implications of findings

In the introduction of this thesis, three areas of the potential contribution of UA to a sustainable future were identified: home UA, community and educational UA, and commercial UA. The following sections discuss the implications of the major findings of this research for each of these areas, including recommendations for improvements.

For home UA

Of the home gardeners involved in the EG project, although social connection did not rank highly as a conscious motivation for many, they still demonstrated 'subtle sociability' via their use of social learning sources and their common practice of sharing food with others outside of their own households. There are numerous opportunities within the state of South Australia to share, sell and give away fresh food. These different channels can act as "sticky knowledge structures" of shared emotional and social experiences between food gardeners, others and their wider

communities. If our intent is to improve the sustainable contribution of UA to society, and we want to continue improvements based on evidence, then care must be taken not only in the collection of UA data, but also in how the findings and suggested improvements are communicated and shared. As stated by Carolan (2015 p. 147), "*If a tactic fails to create affective ripples, it is not going to elicit any sort of meaningful change*". Food sharing may help strengthen urban food security by increasing the quantity of fresh, typically local food in circulation. The knowledge, skills and capacity to preserve food, in addition to the distribution and sharing of excess food with others, may also make a valuable contribution to urban food security and the resilience of urban societies (Click 2010; Deppe 2010).

At the household and local government level there is interest in whether producing food in urban spaces can help households save money and reduce their cost of living. Although Australia is a country of relatively high food security overall, almost one quarter of the Australian population depends on government assistance for the majority of their household income (Australian Bureau of Statistics (ABS) 2015). Setup costs in particular were identified in this study as a potential barrier to low-income households. Although 9% of the EG survey respondents reported spending less than AUS$100.00 to establish their food gardens, the median setup cost was AUS$500.00. While the break-even point was estimated at less than 5 years for most, this does not imply that everyone can automatically afford the setup cost.

In addition to the need to consider labour, costs and water as inputs in their own right, we must also consider the impact of these inputs on the economic sustainability of home food gardens. At the beginning of this thesis, it was questioned whether home UA was purely a middle-class discretionary activity. If so, it was hypothesised that home UA could only play a limited role in improving food security on a citywide scale. The results of this research suggest that although many of those currently engaging in UA are relatively well-off financially, it is still possible for people to spend relatively little setting up and maintaining food gardens. Furthermore, if their garden areas are sufficiently productive and resource efficient, to break-even on their costs and begin to save money in earnest.

The issue with considering the implications for citywide food security, however, continues to rest on the high variability in productivity and resource efficiency among people's urban food gardens. If there were some way to consistently improve or raise the productivity and resource efficiency of home UA, this could help increase UA's contribution to urban food security.

One potential way to help improve the success of home UA is by providing additional guidance. The results presented in chapter 6 advocate a new way for gardeners to decide what kind of food garden would best suit their household's needs. Home food gardeners can use both their key motivations and their key challenges to help guide the creation of new food gardens, or to re-focus and improve upon existing food gardens. The five main tech-crop categories identified in the EG project have different requirements, trade-offs and returns, all of which can be used to find the best match (or matches) for each household (Figure 4). New gardeners are likely to benefit the most from greater support throughout their first food producing attempts. The EG data demonstrates that although some home gardens do quite well with regards to productivity and resource efficiency, there was also broad variability among the results, and therefore considerable room for improvement.

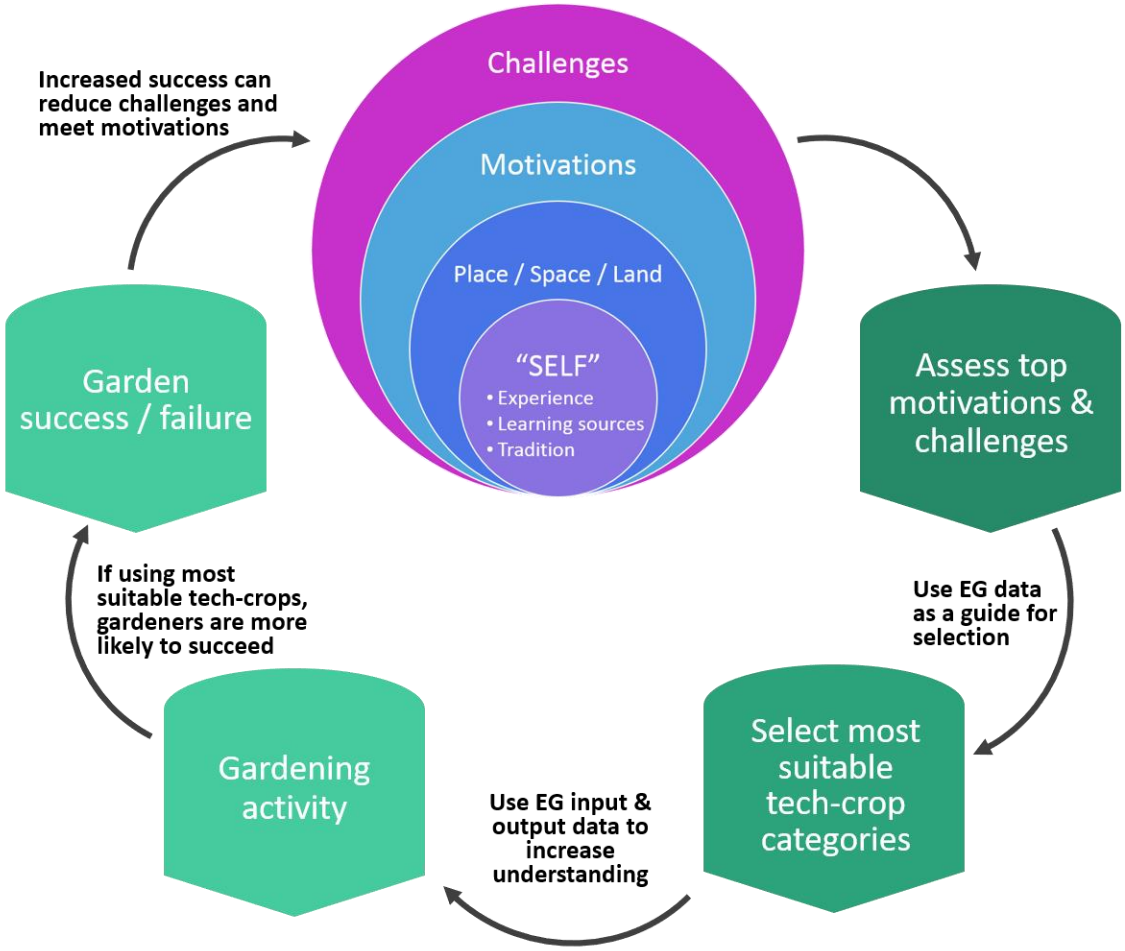

Figure 4. Conceptual model of process to utilise EG data as a guide more the most suitable selection of tech-crop categories to potentially increase likelihood of garden success.

Top recommendations for home gardeners

Utilising several different tech-crop areas simultaneously can help to even out the input requirements and outputs of a whole food garden, provide more consistent year-round harvests and produce the most even (and diverse) combination of fruits, herbs, vegetables and animal products (if desired). Selecting and growing early- and late-season crop varieties may provide another way to save money by producing foods when they are at their most expensive to purchase. Such varieties can also help extend harvest periods.

For households with cost as their greatest challenge, the EG survey respondents reported a variety of ways to help reduce initial setup costs, including, salvaging materials, finding them for free or buying them second-hand, growing plants from seed and making their own compost from garden cuttings and food scraps.

Importantly, growing vegetables, herbs and other crops in in-ground beds, or planting fruit trees in the ground were found to have the lowest set-up costs per square metre.

For those gardeners concerned about time, this research revealed that producing food at home does not take as much time as the EG survey respondents originally estimated. Reasonable returns can be gained from investing approximately 1.5 hours per week. Harvesting and irrigating took the most time, thus investing in labour saving methods for these activities can help reduce the time required to grow food. The tech-crop category with the lowest time requirement was bed-orch, followed by bed-veg/vegh/herb/other and chkn-egg.

Water is a fundamental requirement of all food production. The cost of mains water was for most of the EG gardens relatively low. However, as the cost of mains water will likely increase in the future, care should still be taken to conserve water where possible. Consideration of alternative water sources is also encouraged. Originally, the survey respondents demonstrated a low awareness of how much water they were applying to their gardens. Gardeners can improve their understanding of the volumes of water being applied to their gardens via the use of water meters or flow meters. The high reported variability in the WUE_{fin} scores of the EG gardens included some scores which were less than the cost of the water itself, while other scores were as much as 20 times higher than the cost of the water. In areas and stituations where water is scarce and/or expensive, there is an opportunity to optimise. Chkn-egg areas presented the highest WUE scores, particularly with WUE_{nut}.

While the EG survey respondents did cite "lack of space" as both a top initial and a top ongoing challenge, the results from the collected EG garden data indicate that smaller gardens, for example those less than $20m^2$, are typically more productive per unit area than larger gardens. This is good news for those concerned about growing food in smaller urban spaces.

For community and educational UA

None of the community gardeners who completed the survey were willing to go on and collect data on their community food garden. Three community gardens were

visited to discuss the project, but engagement of the gardeners required the building of stronger relationships than existed at the time. Although the results and information presented in this section are based upon small survey samples sizes, the findings were still considered worth sharing.

From their online survey responses, the EG community gardeners were found to have higher levels of social capital than home gardeners and were twice as likely to have participated or organised a group gardening activity. They also more actively valued "social connection" as inter-household community focused social connection. Yet similarly to the home gardeners, the EG community gardeners also typically shared food with others.

Further research is recommended into the potential flow-on influence of community gardens into the wider surrounding communities in which they exist, in addition to their value as collective keepers of food production knowledge, skills and tools, and their productive capacity and resource efficiency.

In the end only two school gardens registered with the EG project, and of those, only one engaged a group of older students to consistently enter the input and output data collected into the EG online database. The effort required to engage a school required considerably greater time than engaging home gardeners. A relationship had to be developed, to help the schools understand the benefits of them being involved and the expectations for data collection. A 'school engagement model' was developed (as presented in Appendix A) and is recommended for use in future school garden research.

Although the popularity and numbers of school gardens around Australia and in South Australia continue to grow, certain aspects of the learning potential from these gardens remain overlooked – including education around the production of food itself (Uhlmann et al. 2018; Yeatman et al. 2013). Introducing basic measurements and monitoring of the inputs and yields of school gardens by the students, could improve practical food production knowledge and act as a pathway for "hands on" garden-based learning of STEM (Science, Technology, Environment and Mathematics) topics.

The development of a future project is encouraged, particularly one which focused purely on school food gardens and the potential improvements from the addition of a simple measurement and monitoring program linked to the STEM curriculum.

For commercial UA

While the EG project did not target the small-scale UA businesses which currently exist in South Australia, it did collect a large body of input and output data on existing home gardens. These data provide baseline information on the productivity and resource efficiency of home food gardens, some of which can be utilised by existing UA businesses, or those interested in scaling up home gardens into new UA businesses. Indeed, the scaling up of home gardens may well be the only way that small UA businesses occur. Large-scale farmers are unlikely to go against current trends and downsize to a smaller urban plot. Therefore, it is pertinent to consider home gardens as the potential building blocks of future commercial UA businesses.

Insights for commercial UA applications

Setup costs, even for small-scale production, may represent a considerable challenge if scaled up for commercial UA ventures. Although there are ways to help reduce setup costs (as discussed in chapter 6), they may be harder to apply to commercial situations. A simpler approach may be to consider the average setups costs of the different tech-crop categories identified in this research to help justify the most suitable type of production. The price of mains water was reasonably low for most of the EG gardeners; yet for the potentially larger scale of a commercial UA operation, consideration of alternative water sources, highly efficiency irrigation systems or optimised crop selection would be sensible if intent on reducing costs from the outset.

Harvesting and irrigation took the most time, therefore identifying or developing labour-saving techniques for one or both activities would help reduce labour requirements. While the EG home gardeners spent less time than they originally estimated, applying a wage-rate to the labour considerably reduced their potential savings (or profits). If gardening is taken as a hobby with time as discretionary, then the median hourly return rate of AUS$9.91 could be considered reasonable. However,

if a commercial return on labour is required in a small business, only the top 18% of the EG gardens provide scalable exemplars.

It is hoped that this dataset will form the basis of a larger collection of baseline information which can be used to help inform a framework of sustainable UA business cases. There remains a lack of a trusted body of knowledge and data to provide industry benchmarks for the process of UA commercialisation.

Research Limitations

While the research presented in this thesis is expansive, it is important to recognise the limitations of this study. These limitations are outlined below.

The online survey and recruitment

- While the EG project did managed to engage (and select for the garden data collection), a wide variety of gardeners (ages, experience levels, motivations and challenges) and gardens (sizes, cultivation techniques, crops, water sources, irrigation methods and levels of food sharing), the project could have benefited from a wider variety of urban food gardeners. Consideration and deliberate inclusion of participant's cultural backgrounds, heritage, migrant or minority status, income levels and sexual orientation would have broadened the research and assisted in investigation of any systemic barriers to participating in UA experienced by any particular group of people. As a project of the Discovery Circle, there was some potential bias of survey respondents and participants due to the high level of engagement of the Discovery Circle Initiative members – many of whom are well-educated, relatively well-off older couples or families with younger children.

- Low numbers of community gardeners responded to the online survey and none willing to continue and participate in collecting garden data. This required more time than feasible to develop a relationship and understanding of the community gardener's needs – but would have allowed for greater comparison between the productivity and resource efficiency of home and community gardens.

- Low numbers of school gardeners responding to the online survey, with only 2 registering to collect data and one school garden participating consistently. Again, greater time to develop relationships with schools would have increased the numbers involved, but more school gardens involved would have allowed a review of the productivity and resource efficiency of school gardens – including reporting of how the harvested food is used.

The scope of the research

- Besides investigating the efficient use of resources and some recycling of wastes via composting, this research did not consider the environmental or ecological relationships with UA. This research also did not consider the potential environmental benefits of growing your own food from a life cycle assessment standpoint. Consideration of more environmental factors would have strengthened the full circle 'sustainable' perspective on urban food gardens.

The inputs, output and garden aspects measured

- Although the names of all harvested crop types were reported, the EG project could not collect data on inputs required by individual crops. Therefore, results or guidance on the best individual crops for an optimised crop selection cannot be calculated.

- Fertiliser applications as types or volumes were not measured. This would have provided some insight into any relationship between types of quantities of fertiliser applied to different gardens.

- Soil type and composition were not considered or tested by this research. No data were collected on the type or composition of the soils involved in each of the garden areas as there was such a mixture of garden areas: in-ground, raised beds, wicking-beds, pots and planters, vertical gardens, aquaponics systems, bee hives and poultry yards. Inclusion of soil analysis would have allowed for investigation into any relationships between soil type and garden results, for example whether gardens with adequately nourished and amended soils were more productive. The EG participants likely prepared their soils in different

ways, some more thoroughly than others. As variations in soil health and levels of organic matter may have influenced the productivity of each food garden, future research on this facet of urban food gardens is encouraged.

- Similarly, soil contamination was not investigated by this research. Soil contamination is a potential health issue for urban gardeners. Considerable research has already investigated the various facets of soil testing (Rouillon et al. 2017), the importance of considering the historical uses of a site (Kessler 2013; Ramirez-Andreotta et al. 2013), the benefits of soil amendments such as compost or phosphorus additions (Attanayake et al. 2014), and methods of soil remediation or management (Clark et al. 2008; Kessler 2013; Ramirez-Andreotta et al. 2013; Sinclair Knight Merz 2013). However, of the 180 listed challenges of the EG research relating to "Unsuitable space, soil and climate" only four mentioned unsuitable soils due to possible contamination or concern of contamination. It did not appear to be a common challenge for the EG respondents, although whether this was due to lack of concern of a lack of awareness remains unclear.

- While this thesis only considered rainwater harvesting from a South Australian perspective, it is conceivable that UA conducted in other semi-arid or arid locations where rainwater harvesting is more viable (for example, with a shorter and less severe dry season), would show a stronger preference for this water source. However, it is also conceivable that such locations or climates might in-turn also have inherently cheaper mains water which could out-compete the cost of collecting rainwater.

Opportunities for further investigation

This research developed and demonstrated a variety of new methods, approaches and equations to support the expansion of future UA research. It also collected a large range of input, output and garden setup data which has helped to increase the understanding of existing urban food gardens and can be used as baseline data.

There is still a need for continued collection of consistent and comparable data on other existing forms of UA. Five key directions for recommended future research are as follows:

1) Continuation and expansion of data collection: further investigation to increase available data on multiple tech-crop categories. This future research could also test the most effective ways to help guide and improve the results from urban food gardens, potentially by assessing the key motivations and challenges of urban gardeners and applying those to the existing EG data to guide in most suitable tech-crop choices.

2) Creation of a similar project with a focus on the potential for a supported home garden program to help low-income households: this research could be set up similarly to the 'La Mesa Verde' in California USA, as reported by Gray et al. (2014) and Algert et al. (2016). However, instead of supporting only one type of cultivation technique, the program could apply the knowledge from the EG project to guide each household's choice of the most suitable tech-crop category for that household.

3) Research into the impacts of housing tenure and employment status on people's capacity to have a food garden and implications for upscaling. One aspect of this research could investigate better support from landlords of rental houses for tenants interested in producing some of their own food. For example, both fruit trees (in-ground) and keeping chickens emerged as two prominent and popular types of food production; however, they both require long-term commitment which may not suit renters. If landloards installed fruit trees and the structure of a poultry run, it would allow tenants the opportunity to make use of the UA infrastructure.

4) Potential application of basic measurements approach to complement the existing structure of the Stephanie Alexander Kitchen Garden Program (an Australian gardening program for schools): an additional facet of the program could be designed to provide support and resources to schools who wish to improve the use of their school gardens as venues for practical hand-on STEM (Science, technology, engineering and mathematics) related learning. The project could work with a variety of schools to learn what would most benefit them while also not placing undue

pressure on those managing the school gardens. A more STEM-based school garden approach may also increase the appeal to those high schools currently lacking a school garden.

5) Further investigation into food preservation, food waste and food distribution: Future research could study ways to help improve urban gardeners' knowledge of how to preserve food safely, whether home-grown food is more highly valued than store-bought food and the implications for food waste, and how to support the different avenues for food distribution. 64% of the EG survey respondents reported that they didn't grow more food than they thought their household could consume. And yet around Adelaide, there are currently multiple avenues for people to share, swap, sell, or donate additional food. Such research could also consider the possible additional flow-on effects of research into urban food gardens and whether encouraging people to measure the resources required to grow food for themselves, may cause them to consider more fully the environmental footprint of the food they purchase. This could, in theory, lead to people making more informed food choices.

6) Using the EG data and documenting the formation of any new UA businesses to begin development of sustainable UA business cases: a new project could monitor any new UA businesses forming and investigate potential 'success factors' of UA businesses. The development of "best practice" from case studies in exemplary gardens could help guide the design and optimisation of viable UA businesses.

Conclusion

UA remains a complex and variable field of research. Nevertheless, the research in this thesis makes two significant contributions to the field. Firstly, the data collected by the EG project provides a deeper understanding of the productivity, resource efficiency and social value of urban food gardens, particularly home food gardens in South Australia. Secondly, the methodological developments, recommendations and demonstrations provide practical support and guidance for the expansion of future UA research, enabling the collection of more consistent and comparable data on larger numbers of existing urban food gardens.

As the most common form of UA in Australia, home gardens collectively represent the greatest potential contributors to future urban food production. Taylor and Lovell (2013) called them the, "ever-present, more durable form of urban agriculture". We do not yet know whether UA as its own commercial industry will flourish, or what impact such an industry may have. But we can encourage and nurture opportunities for home food gardeners to share knowledge and experiences and continue their co-experimentation of creating our collective urban food future. The research presented in this thesis should inform (and hopefully inspire) improvements in the productivity, resource efficiency and ways to potentially increase the flow of fresh food from urban gardens to others. It is these different kinds of worth that may well contribute the greatest sustainable impact upon our urban landscapes, urban food systems and our collective future.

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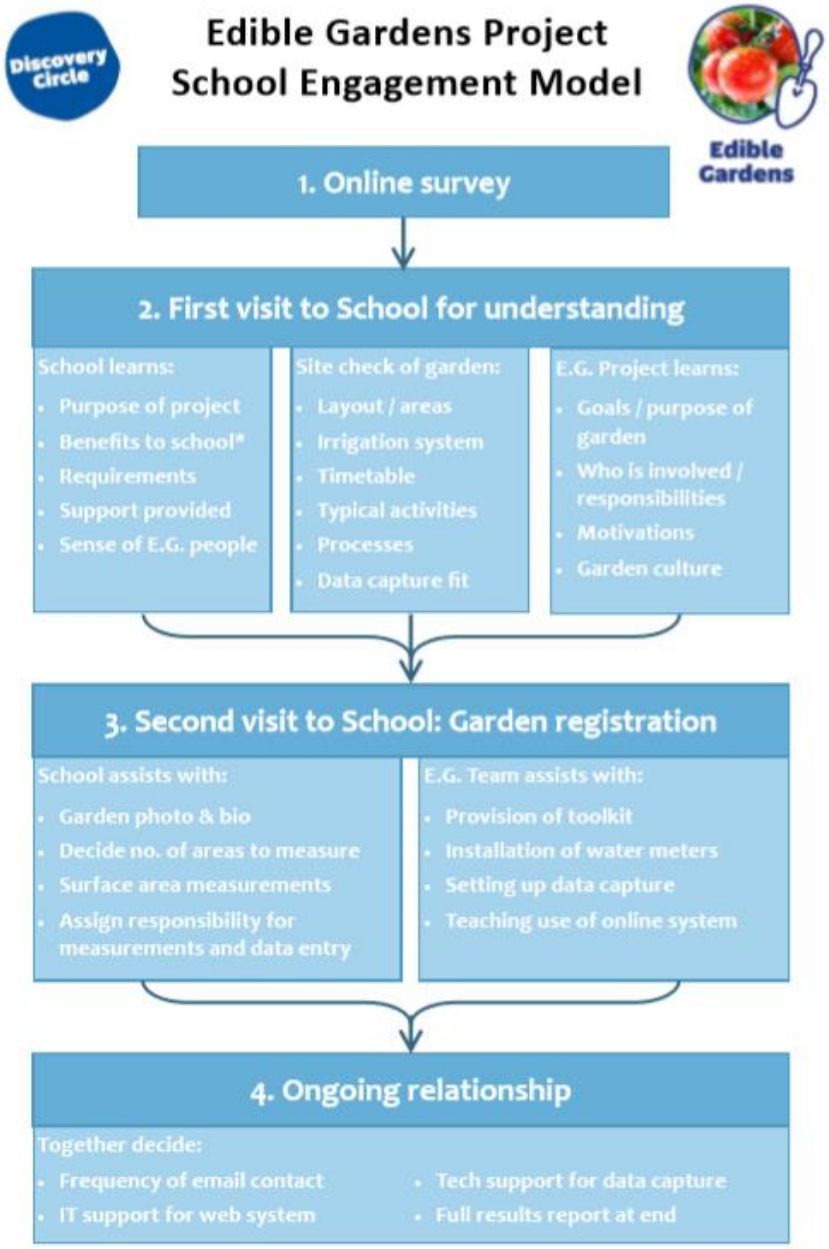
Appendix A Additional Work from Chapter 2

The School Engagement Model

This model was developed to demonstrate to schools considering participation in the Edible Gardens Project, how the relationship would work.



Benefits to the School

Participation in the Edible Gardens Project provides:

- A simple practical way to measure, record, analyse and display the inputs, yield and water efficiency of the school garden.
- Records which can help communicate the productivity of your garden to parents, the School Board and funders.
- Opportunity for students to apply STEM skills in a garden setting.
- Students can access the chart results page in computer classes - there they can compare the results of their garden with other schools.
- Opportunity for selecting student leaders from older year levels (years 6 & 7) to be responsible for measurement and data entry.
- School can download complete copy of their data to analyse and use as they wish.
- Complements the Stephanie Alexander Kitchen Garden Initiative by providing a way to measure the ongoing productive benefits and success of the school garden.

Interested in learning more about the Edible Gardens Project?

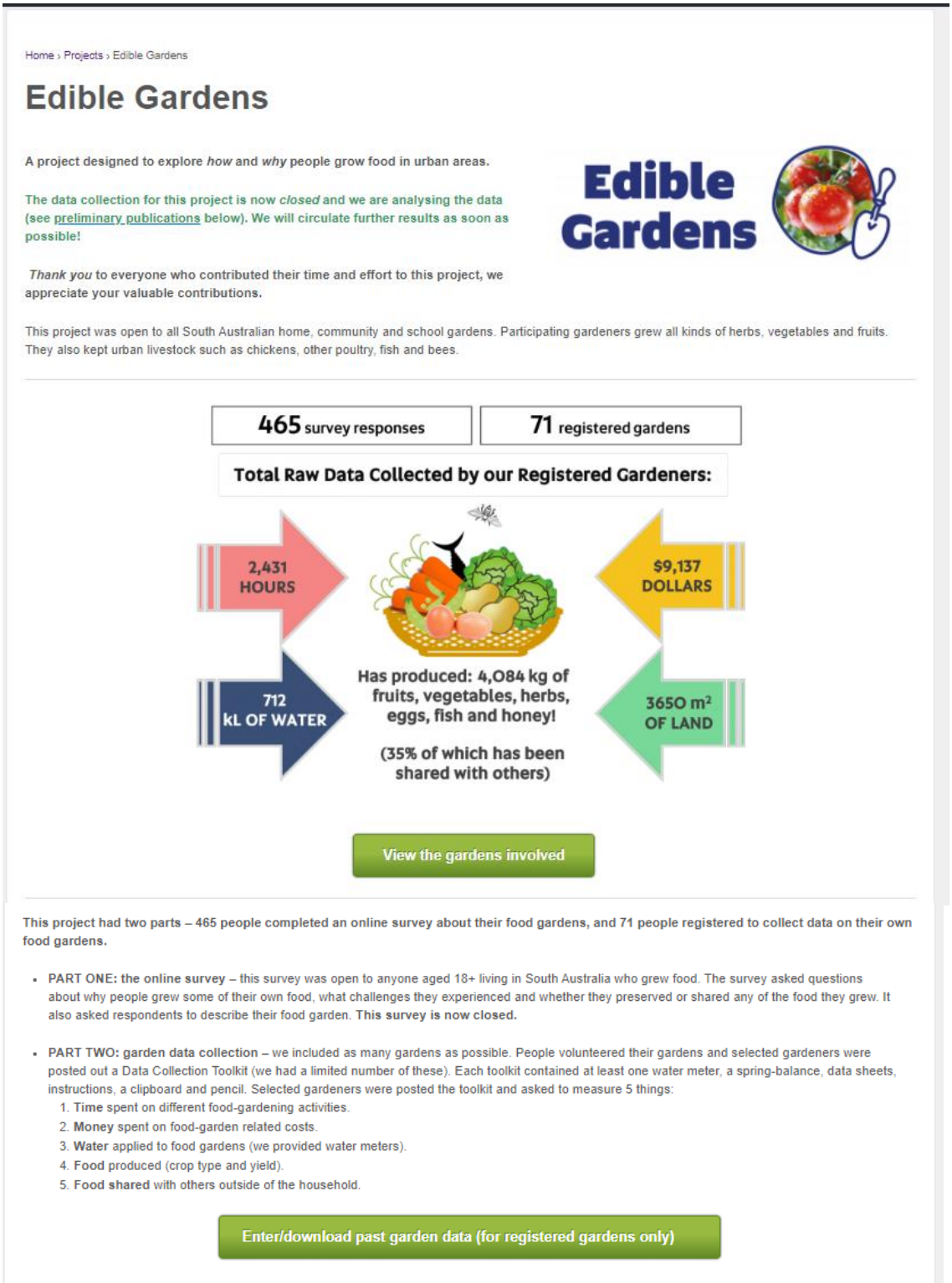
Visit the Discovery Circle website:
www.discoverycircle.org.au/projects/edible-gardens/
Or contact The Discovery Circle via email:
discoverycircle@unisa.edu.au

This project is supported and funded by:

University of South Australia
Government of South Australia
Natural Resources Adelaide and Mt Lofty Ranges
MARION
Salisbury

Screenshots of the Edible Gardens Website

The homepage



Home › Projects › Edible Gardens

Edible Gardens

A project designed to explore *how* and *why* people grow food in urban areas.

The data collection for this project is now *closed* and we are analysing the data (see preliminary publications below). We will circulate further results as soon as possible!

Thank you to everyone who contributed their time and effort to this project, we appreciate your valuable contributions.

Edible Gardens

This project was open to all South Australian home, community and school gardens. Participating gardeners grew all kinds of herbs, vegetables and fruits. They also kept urban livestock such as chickens, other poultry, fish and bees.

465 survey responses | **71** registered gardens

Total Raw Data Collected by our Registered Gardeners:

2,431 HOURS

$9,137 DOLLARS

712 kL OF WATER

365O m² OF LAND

Has produced: 4,O84 kg of fruits, vegetables, herbs, eggs, fish and honey!

(35% of which has been shared with others)

View the gardens involved

This project had two parts – 465 people completed an online survey about their food gardens, and 71 people registered to collect data on their own food gardens.

- **PART ONE: the online survey** – this survey was open to anyone aged 18+ living in South Australia who grew food. The survey asked questions about why people grew some of their own food, what challenges they experienced and whether they preserved or shared any of the food they grew. It also asked respondents to describe their food garden. **This survey is now closed.**
- **PART TWO: garden data collection** – we included as many gardens as possible. People volunteered their gardens and selected gardeners were posted out a Data Collection Toolkit (we had a limited number of these). Each toolkit contained at least one water meter, a spring-balance, data sheets, instructions, a clipboard and pencil. Selected gardeners were posted the toolkit and asked to measure 5 things:
  1. **Time** spent on different food-gardening activities.
  2. **Money** spent on food-garden related costs.
  3. **Water** applied to food gardens (we provided water meters).
  4. **Food** produced (crop type and yield).
  5. **Food shared** with others outside of the household.

Enter/download past garden data (for registered gardens only)

Data collection

What did this involve?
Selected gardeners were sent a registration email, with instructions for how to register their garden in the Edible Gardens system. Once registered – we posted people out a Data Collection Toolkit. The toolkit contained all the tools and information they needed to help them collect data on their garden.

This part of the project was quite "hands-on" and our participants were prepared to keep their clipboard and blank data sheets (provided in the toolkit) near them while they worked on their food gardens. They needed to think about how much time they spent on different gardening activities, such as "planting/sowing", or "pest control". They also needed to check their water meters regularly to see how many litres of water were applied to their food gardens.

How much time did this take people?

- Registering gardens took approximately **15 minutes** – we asked people about the different garden areas they chose to collect data on, such as size, type of area, water source/s and irrigation method/s.
- It took most gardeners around **½ an hour** to familiarise themselves with the toolkit and install the water meter/s.
- Typically, ongoing data collection took **10-15 minutes per day (on the days participants tended their gardens).** This time included the recording the amount of time spent, any water applied and weighing any produce harvested.
- Entering data online typically took between **10-20 minutes (once a fortnight)**. Once data were entered and saved, online results were automatically updated (see the data charts for each garden).

What did people get in return for collecting data?

Downloadable data and interactive online charts for easy comparisons: All the data a participant collected and entered into our system was available to download for their own records and analysis. When they entered new data, their results were automatically displayed as interactive charts (see the data charts for each garden). With these charts you can compare separate areas in one garden for their water use, time spent, harvest yield and water use efficiency. You can also compare one garden with any other gardens in the ***Edible Gardens*** project. These charts can be downloaded and saved by anyone.

A nutritional and retail value report on all the results from their food garden: our participants will be sent a final report. This report will provide results from their different garden areas, plus information about the nutritional and retail value of the food they grew. Our nutritional data analysis was based on commercial nutritional values from the NUTTAB database. Our retail value analysis was based on supermarket produce prices tracked over the life of the project.

Why did we need your help?

Because everyone grows food in different ways and for different reasons! We wanted to learn as much as we could about urban food gardens, but we are a small team of scientists and can't visit and monitor enough food gardens by ourselves. This is where Citizen Scientists came in. Members of the public helped our research by answering our online survey, and volunteered to collect data on their own food gardens.

Growing food in urban areas is also known as "urban agriculture", (see our blog to learn more). Previous research has found that **over half of all South Australian households grow some of their own food!** However, we still know very little about how much food these urban gardens can produce, or how much time, money or water it takes to grow that food. This kind of information is important for a numbers of reasons:

"Does the way you grow food best match the results that you're after for your garden?"

For example, you might want to grow lots of food but not use too much water – but without measuring the amount of water you apply to your food garden, how can you know if what you're doing is working? Or what if you want to save money? Do you track your costs?

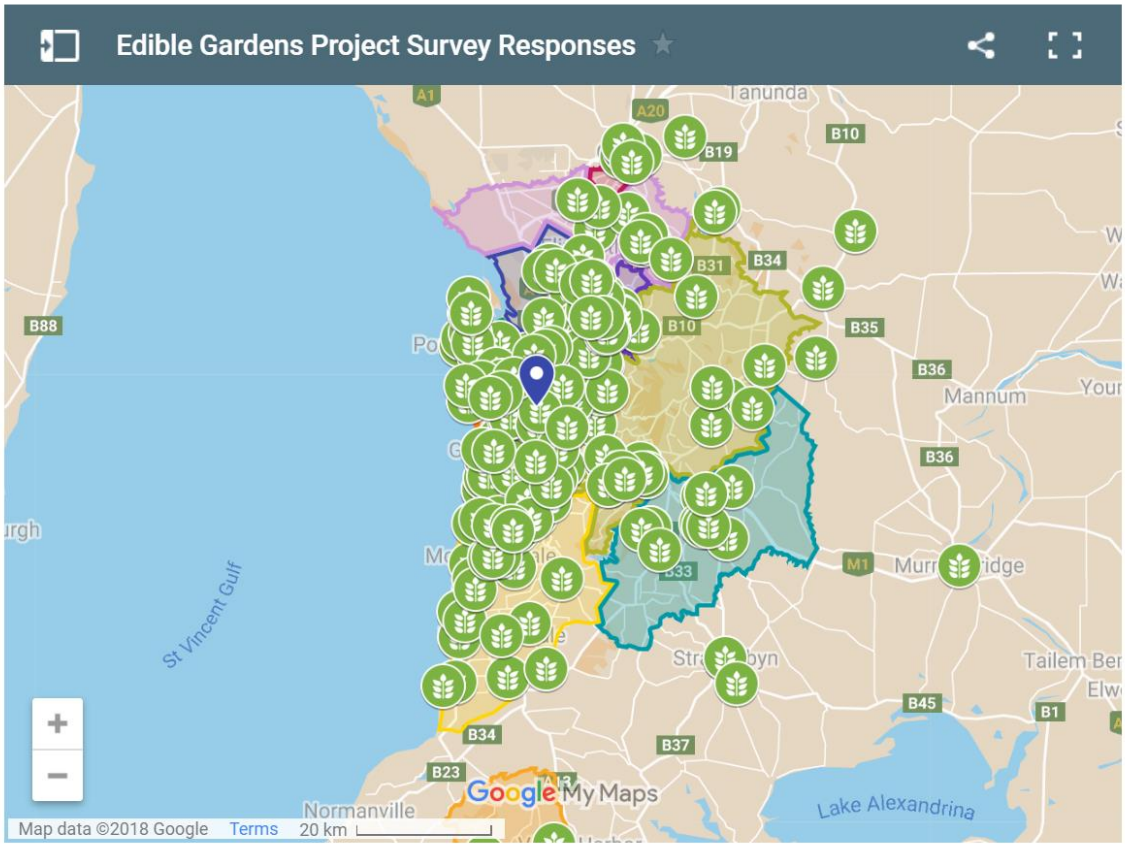
By collecting data on all different kinds of real food gardens, we can start to become more aware of what goes into and what comes out of our food gardens.

Our progress so far

Although both Phase 1 and Phase 2 (the data collection parts) of the project are now closed – we are still working on analysing, comparing and calculating the HUGE amount of data that everyone has contributed!

View the gardens involved

Below you can see how many people have participated in the Edible Gardens online survey and the spread of suburbs and postcodes across South Australia. **Please Note**: no individuals' address is identified (this map shows suburb or town markers only). **Click on the map to enable zooming and moving the map!**



Reports, Publications & Presentations

Here you can find scientific publications, reports and project updates on the *Edible Gardens* project.

- "The Case for Citizen Science in Urban Agriculture Research", Pollard, G.; Roetman, P. & Ward, J., *Future of Food: Journal on Food, Agriculture and Society*, 2017, Volume 5, Issue 3, pages 9-20.
- "Typically Diverse: The Nature of Urban Agriculture in South Australia", Pollard, G.; Roetman, P. & Ward, J., *Sustainability*, 2018, Volume 10, Issue 4.



Edible Gardens Project at CitSciOz18 Adelaide Conference from Georgia Pollard on Vimeo.

Questions & Answers

- **Why is data collection closed now?**
  We've wrapped up the Edible Gardens project after 1 year and 7 months of data collection. We have a large quantity of valuable data collected with considerable effort (thank you again to everyone involved)! Now it's time to analyse our results, so that we can share what we've learnt.
- **I'm a current registered participant, can I keep collecting data for myself?**
  While we are no longer collecting data, we encourage people to continue. Our online system has closed, but if you download your data as an excel spreadsheet you can continue to monitor your inputs and yields in your own spreadsheet.
- **I'm interested in hearing about the results from this project, where can I find out more?**
  To stay informed about our program, including results from Discovery Circle projects and opportunities to participate, please register for our eNewsletter. Additionally, check out the collection of reports, publications and presentations in the section above.
- **This project sounds really interesting! Is it open to any other states in Australia, or other countries?**
  A great deal of time, money and work went into developing all the online infrastructure for this project. We are keen to make the project infrastructure available to others. Please contact us (details below) if you would like to know more.

Project team

- Georgia Pollard (PhD candidate)
- James Ward (School of Natural and Built Environments, UniSA)
- Philip Roetman (Discovery Circle, UniSA)

Contact us and stay in touch

- **Contact us:** if you have any questions, please contact us by **email** discoverycircle@unisa.edu.au or by **phone** (08) 8302 9999.
- Follow our facebook page: www.facebook.com/thediscoverycircle
- Sign up for our e-Newsletter (click here)

The Discovery Circle is a collaboration between

University of South Australia · Government of South Australia, Department of Environment, Water and Natural Resources · Natural Resources Adelaide and Mt Lofty Ranges · City of Marion · City of Salisbury

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Participating gardens page

Home › Projects › Edible Gardens › Participating Gardens

Participating Gardens

On this webpage you can see all the food gardens that are currently participating in the *Edible Gardens* project. You can also view the results of any particular garden by clicking the "View Results" button next to their garden picture.

How do I search for a particular garden?

You can search for a garden in a few different ways (as the project develops, more gardens will be available):

1. **If you know the name of the garden,** you can type it into the search box at the top left of the list of gardens (below).
2. Or, you can select what **type of production method** (for example, raised garden bed, pots or planters, or chickens).
3. Or, you can search by the **type of produce the garden is growing** (for example, vegetables, herbs, or fish).
4. Or finally, you can select whether **you only want to see home food gardens, or only community gardens, or only school gardens.** Do this by ticking the box next to one of the symbols on the top right hand side of the gardens list.

Search... Production: All Produce: All

4H VIEW CHARTS

We live on the outskirts of Murray Bridge in an area known as White Hill due to the white sandy soil. For this reason we grow in raised beds with soil brought in. We have been growing for a number of years and are continually learning and adapting our processes. One of the best activities from our garden is making sauces, pickles, jams and pastes from the produce. Picking and eating berries and corn straight from the garden make all the effort worthwhile.



Banksia Park School R-7 VIEW CHARTS

Banksia Park Primary School opened in 19 64 as separate primary (Years 3 to 7) and junior primary schools before amalgamating in 19 94 to become an R to 7 school. The school is located within the Tea Tree Gully council area adjacent to the Banksia Park Family Kindergarten and within walking distance to Banksia Park International High School. The school is well-resourced and set in attractive, well-maintained grounds.



Dogs who eat their greens

VIEW CHARTS

I have 6 veggie beds, four are 2.5m x 1.2m whilst the other two are 1m x 0.8m. I rotate through all except one of the smaller beds, which is dedicated for my asparagus and tarragon. I have to put shadecloth barriers up around the beds growning leafy greens as our 2 Dachshunds - Norm and Monty - are addicted to my veggies and will quite happily help themselves if they get a chance. I have 3 apples trees (grafted onto the one root stock), an apricot tree, 2 x lemon trees, a grapefruit, a lime, a fig tree and 2 almond trees - though the birds get the almonds and the figs. We have 3 chooks, all with names (Ramen, Udon and Karaage), with 2 of them laying an egg a day each. Ramen is now 5 and a 1/2 and definitely enjoying her retirement.



1 2 3 4 5 6 7

1 - 10 of 68 gardens

Questions & Answers

Can't see your garden listed here?
Have you completed the online survey, received a confirmation email and registered your garden? Once you have registered your garden it takes approximately 5 minutes for your garden to be displayed here in the list of participating gardens.

Completed the survey but haven't yet received your confirmation email?
Wait at least a week (or check your junk email folder!). If after one week it still hasn't arrived, please contact us using the email address below.

Want to get involved in the *Edible Gardens* project?

Go to the project webpage to find out more (click here).

Contact us

You can contact us via email: discoverycircle@unisa.edu.au
Or by phone: 08 8302 9999

Edit

The Discovery Circle is a collaboration between

University of South Australia
Government of South Australia
Department of Environment, Water and Natural Resources
Natural Resources Adelaide and Mt Lofty Ranges
City of Marion
Salisbury

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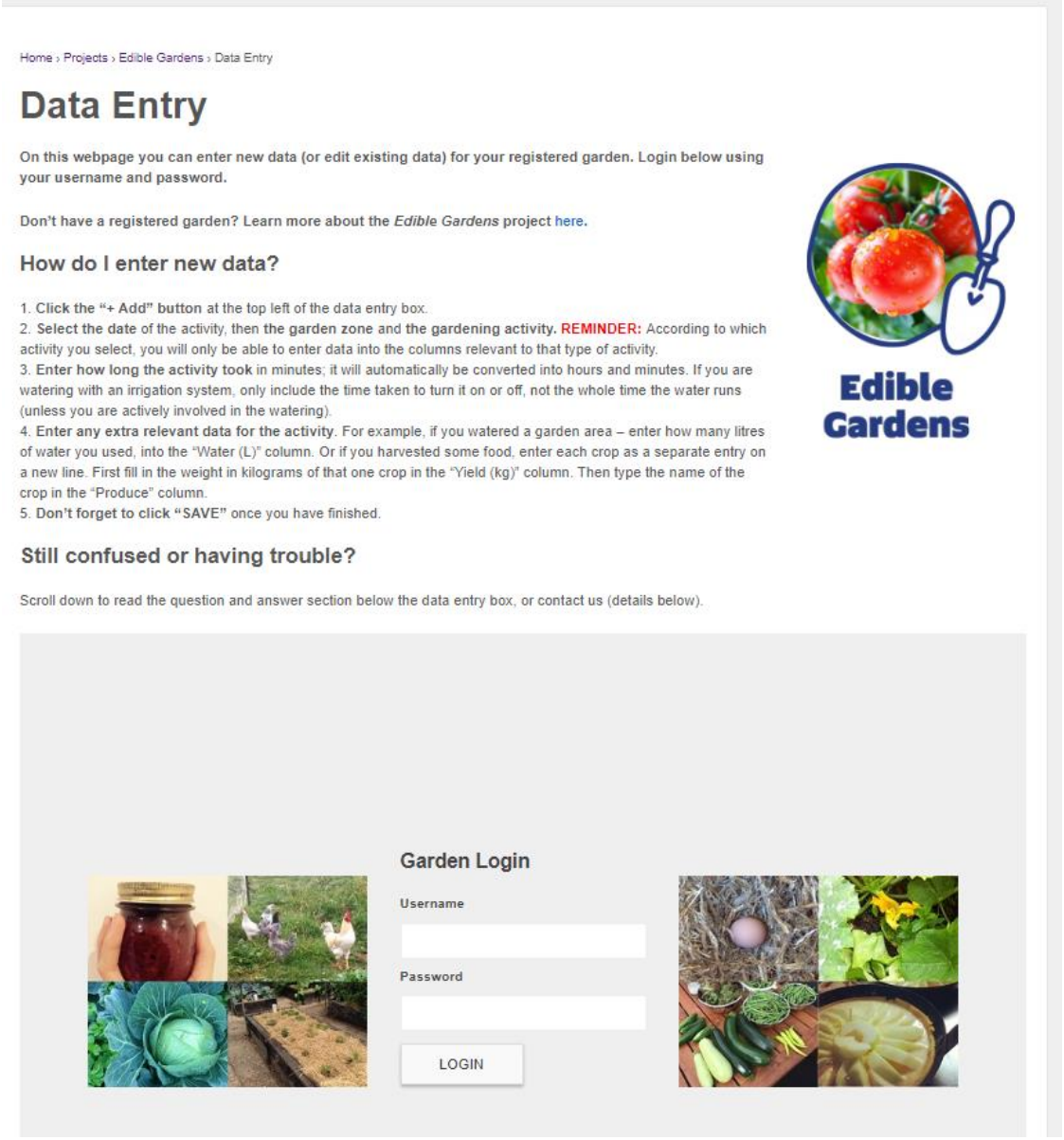
Data entry page

Before logged in.



Questions & Answers

How do I edit existing data?
You can edit any of your existing data by clicking on the "Edit" button on the top left of the data entry box. Then you can click on any listed entry and change the details or even delete a whole record.

What if I forget to record some of my harvest?

If possible, please make an estimate of your "forgotten" harvest (you can base your estimate on previous harvests) and make sure you add an asterisk (*) to the produce name (so that we know it is an estimate).

How do I download my garden data?
You can download all your garden data by clicking on the "EXPORT" button at the top middle of the data entry box. Select if you would prefer your data to download as an "Excel" file or as a "Csv" file.
The download will then begin and you can save the file to your computer.

If I select "Whole Garden" as my garden zone, why is "Purchasing" the only activity I can enter?
So that we can display your data properly in the charts and compare it with data from other gardens, we need to be able to keep your data separate for each of your Garden Areas. Otherwise we can't compare just one of your Garden Areas with just one of someone else's Garden Areas.
"Purchasing" is the only activity you can enter if you select "Whole Garden" as your "Garden Area".

What if I swapped some of my produce at a food swap?
If you swapped some of your produce, still record what your produce was and its weight. Then select "food swap" as who you shared the produce with.

What if I shared or gave away seeds or plants instead of food?
If you gave away seeds, cuttings or food plants instead of produce, just write the name of what you gave away in the "Produce" column. Then enter the weight of what you gave away.

I need more blank data sheets, where can I get them?
Just click here to access the printable blank data sheets.
We have updated the datasheet to better reflect the online system, click here to access the new printable blank data sheets (you are welcome to continue to use the old ones too).

Want to collect data on your own food garden?

CLICK HERE TO PARTICIPATE BY COMPLETING THE ONLINE SURVEY

Contact us

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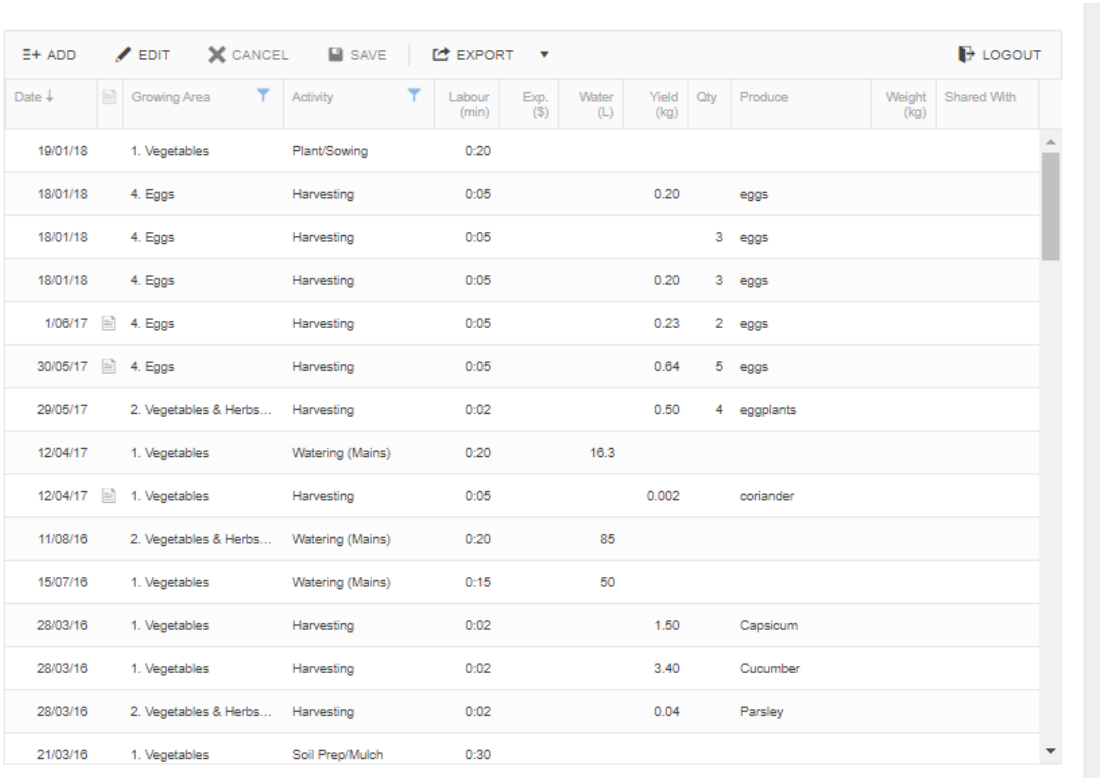
Or by phone: 08 8302 9999

Edit

Once logged in (displaying real data).



Date	Growing Area	Activity	Labour (min)	Exp. ($)	Water (L)	Yield (kg)	Qty	Produce	Weight (kg)	Shared With
19/01/18	1. Vegetables	Plant/Sowing	0:20							
18/01/18	4. Eggs	Harvesting	0:05			0.20		eggs		
18/01/18	4. Eggs	Harvesting	0:05				3	eggs		
18/01/18	4. Eggs	Harvesting	0:05			0.20	3	eggs		
1/06/17	4. Eggs	Harvesting	0:05			0.23	2	eggs		
30/05/17	4. Eggs	Harvesting	0:05			0.64	5	eggs		
29/05/17	2. Vegetables & Herbs...	Harvesting	0:02			0.50	4	eggplants		
12/04/17	1. Vegetables	Watering (Mains)	0:20		16.3					
12/04/17	1. Vegetables	Harvesting	0:05			0.002		coriander		
11/08/16	2. Vegetables & Herbs...	Watering (Mains)	0:20		85					
15/07/16	1. Vegetables	Watering (Mains)	0:15		50					
28/03/16	1. Vegetables	Harvesting	0:02			1.50		Capsicum		
28/03/16	1. Vegetables	Harvesting	0:02			3.40		Cucumber		
28/03/16	2. Vegetables & Herbs...	Harvesting	0:02			0.04		Parsley		
21/03/16	1. Vegetables	Soil Prep/Mulch	0:30							

Preliminary results garden data page

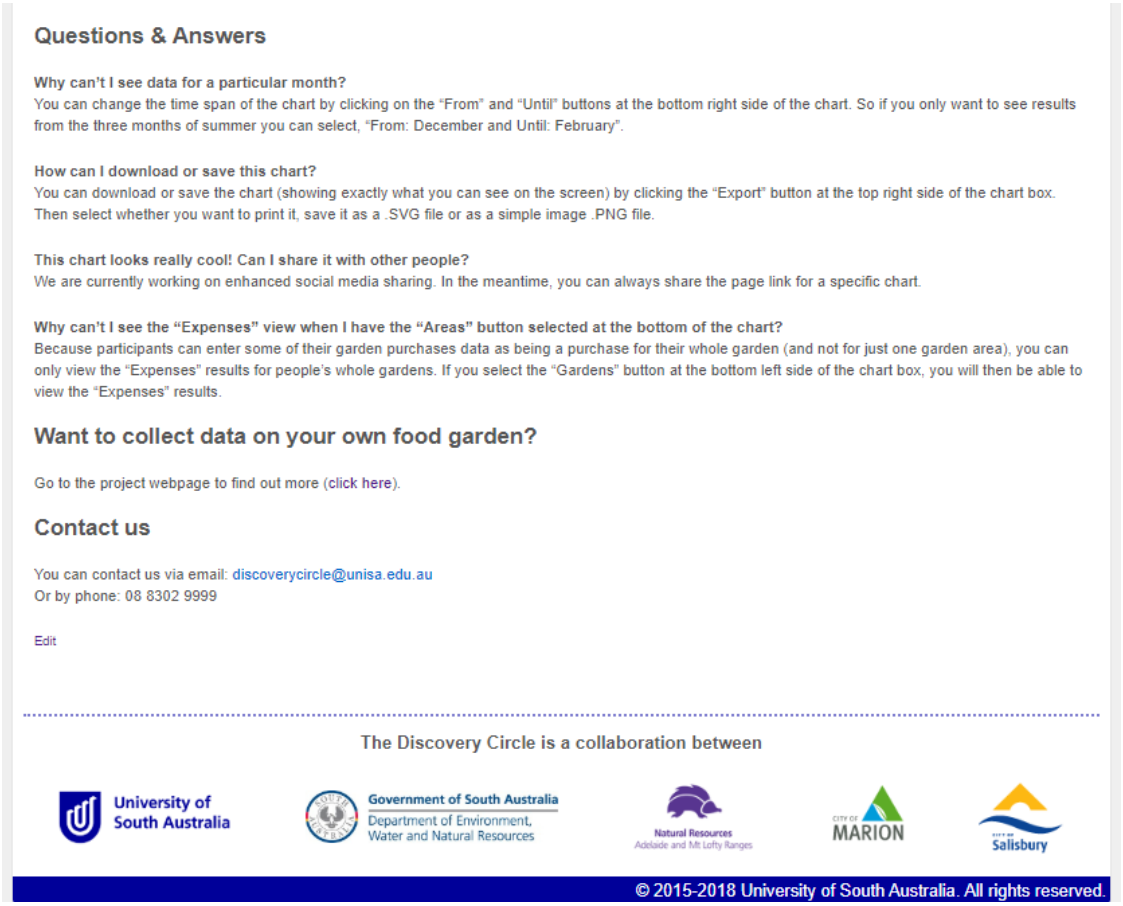
Garden Data

On this webpage you can view the results for each of the participating gardens of the Edible Gardens project. You can even select multiple gardens to compare them!

Chart basics

- Use the options at the bottom of the chart to decide whether you want to **view whole garden results or individual garden area results** (some gardens have more than one area) by clicking the "Gardens" or the "Areas" button.
- Then **click "Search by garden name..."** to search for a particular participating garden, or select any garden from the list.
- Use the buttons at the top of the chart to **move between viewing the Water use, Crop Yield, Expenses, Labour or Water use Efficiency results** for the garden/s or gardens area/s you selected.
- You can also **click "Σ" to view the results as cumulative** (to see the total increasing inputs/outputs over time). Or you can **click "m²" to view the results recalculated per square metre** (which is useful for comparing gardens of different sizes and different types of produce).





Questions & Answers

Why can't I see data for a particular month?
You can change the time span of the chart by clicking on the "From" and "Until" buttons at the bottom right side of the chart. So if you only want to see results from the three months of summer you can select, "From: December and Until: February".

How can I download or save this chart?
You can download or save the chart (showing exactly what you can see on the screen) by clicking the "Export" button at the top right side of the chart box. Then select whether you want to print it, save it as a .SVG file or as a simple image .PNG file.

This chart looks really cool! Can I share it with other people?
We are currently working on enhanced social media sharing. In the meantime, you can always share the page link for a specific chart.

Why can't I see the "Expenses" view when I have the "Areas" button selected at the bottom of the chart?
Because participants can enter some of their garden purchases data as being a purchase for their whole garden (and not for just one garden area), you can only view the "Expenses" results for people's whole gardens. If you select the "Gardens" button at the bottom left side of the chart box, you will then be able to view the "Expenses" results.

Want to collect data on your own food garden?

Go to the project webpage to find out more (click here).

Contact us

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City of Marion
City of Salisbury

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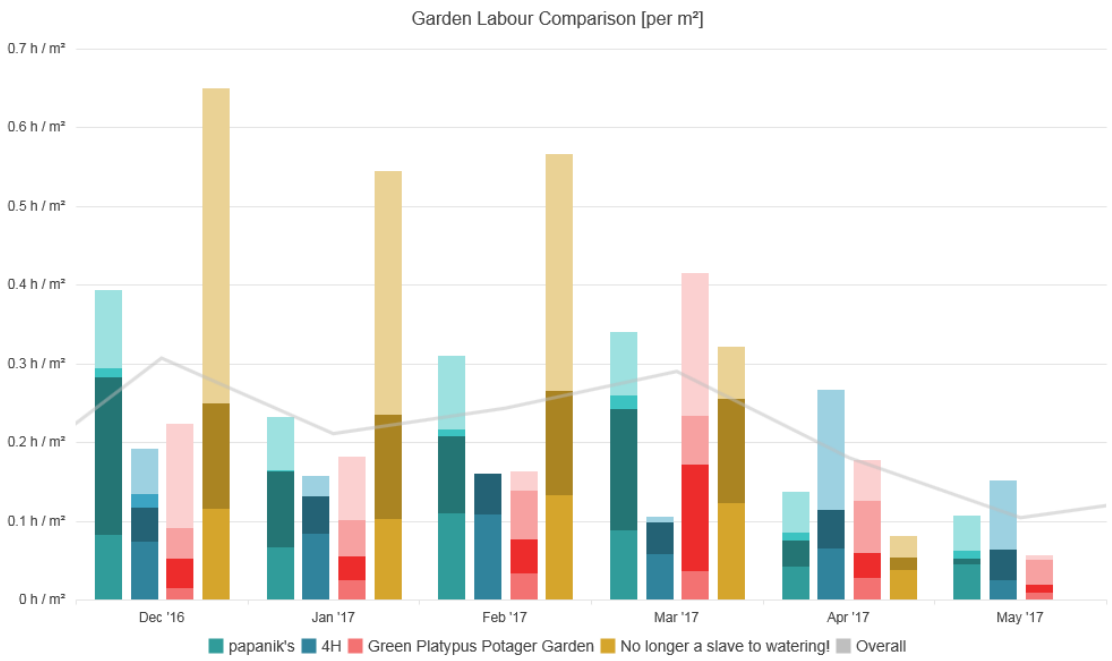
Examples of some different results charts (all charts were public, live, interactive and sharable via a variety of social media.




Water Use
Crop Yield
Expenses
Labour
Water Use Efficiency
Σ
m²
Export
No longer a slave to watering! — Water Use
800 L
700 L
600 L
500 L
400 L
300 L
200 L
100 L
0 L
Sep '16 Oct '16 Nov '16 Dec '16 Jan '17 Feb '17 Mar '17 Apr '17 May '17 Jun '17 Jul '17 Aug '17 Sep '17 Oct '17 Nov '17 Dec '17 Jan '18 Feb '18 Mar '18 Apr '18
No longer a slave to watering! (1. Vegetables & Herbs mixed)
No longer a slave to watering! (2. Vegetables & Herbs mixed)
Average


Water Use
Crop Yield
Expenses
Labour
Water Use Efficiency
Σ
m²
Export
papanik's — Crop Yield
40 kg
35 kg
30 kg
25 kg
20 kg
15 kg
10 kg
5 kg
0 kg
Nov '16 Dec '16 Jan '17 Feb '17 Mar '17 Apr '17 May '17 Jun '17 Jul '17 Aug '17 Sep '17 Oct '17 Nov '17 Dec '17 Jan '18
papanik's (1. Vegetables & Herbs mixed)
papanik's (2. Eggs)
papanik's (3. Fruit from bushes/vines/other)
papanik's (4. Fish & Vegetables)
Average
Gardens
Areas
All
From
Until
papanik's (1. Vegetables & Herbs mixed) ✕
papanik's (2. Eggs) ✕
papanik's (3. Fruit from bushes/vines/other) ✕
papanik's (4. Fish & Vegetables) ✕

Example of a Participant's Final Report



Edible Gardens



Thank you for being part of the Edible Gardens Project!

All the data you collected is helping us to better understand how and why people grow food in urban areas. Thank you!

As a final 'thank you', here is your report. It has been completely customised for your garden, and includes as much information as we could pack into it!

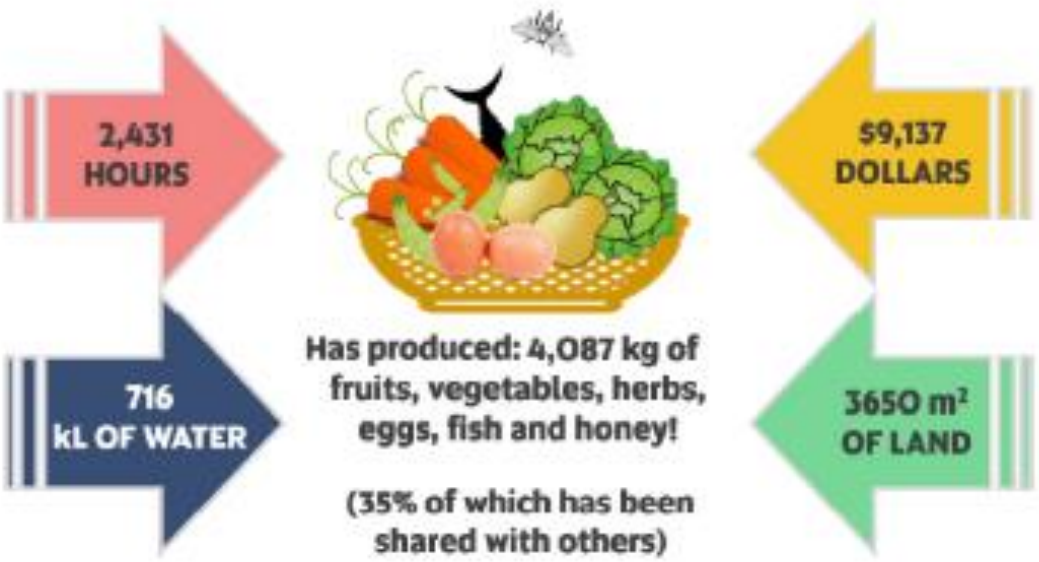
We hope that this experience has given you some food for thought about growing food in urban areas.

All the best,
Georgia, Philip & James: The Edible Gardens Team

Visit the Discovery Circle: www.discoverycircle.org.au
Or email Georgia at Georgia.Pollard@mymail.unisa.edu.au

Summary statistics from the ***Edible Gardens*** Project

Since November 2016 we've had 465 survey responses and 71 amazing gardens (like yours), register to collect data. The figure below shows some raw data totals.



The online survey

Remember the online survey you did at the beginning of the project? We have some results for you. We asked you to rate how much you agree or disagree with some different statements about the value of growing food.

The next page shows the results for what **you** value about growing food, and how your gardening values compare with our other survey respondents.

What you value about growing food:



What this means

The survey statements were grouped into 4 individual factors using Factor Analysis. Below are some examples for each of the 4 factors.

Factor 1: Tranquillity & time out

- People with high scores tended to strongly agree with the value of slowing down in the garden to experience tranquillity, time out and reflection.

Factor 2: Develop skills & learn

- People with high scores strongly valued developing skills, learning and feeling independent by growing some of their own food.

Factor 3: Produce related

- This factor related to valuing healthy, fresh and tasty food and the pure enjoyment of food gardening.

Factor 4: Social connection

- This factor was showed the greatest difference between our home and community gardeners - community gardeners tended to place a higher value on social connection through gardening.
- People with high scores strongly valued their gardening activities as a way to meet new people, and to be around considerate people and other food producers.

papanik's

Garden ID:	100	Total area (m2):	131	Length of data collection (in days)	413

Garden Area No:	Size:	Production method:	Typical crop:	Water source:
1	30	Raised garden bed	Vegetables & Herbs mixed	Rainwater no pump
2	20	Poultry keeping (chooks)	Eggs	Rainwater no pump
3	80	In-ground garden bed	Fruit from bushes/vines/other	Rainwater no pump
4	1	Aquaponics	Fish & Vegetables	Rainwater no pump

Total Inputs

A summary of your total garden inputs:

3,655 L of Mains water at the Tier 2 price of $3.370/kL = $12.32

28,174 L of Rainwater

12 L of "other" water

You recorded $368 in expenses (this may include your one-off costs, but not your water costs).

And spent 349.2 hours tending your food garden.

Total Production

Over your 413 days of data collection you produced:

510.4 kg of food!

Worth $5,304 (based on data gathered at 2 SA supermarkets). Or if you compare it to the cost of certified organic supermarket produce: $11,669 (an increase of 220% in value).

Your produce contains 1168533 kilojules (kJ) of energy (Average daily adult intake = 8,700kJ).

In addition to 21005 grams (g) of protein (Average daily protein = 45-60g for women and 65-80g for men).

Per m²

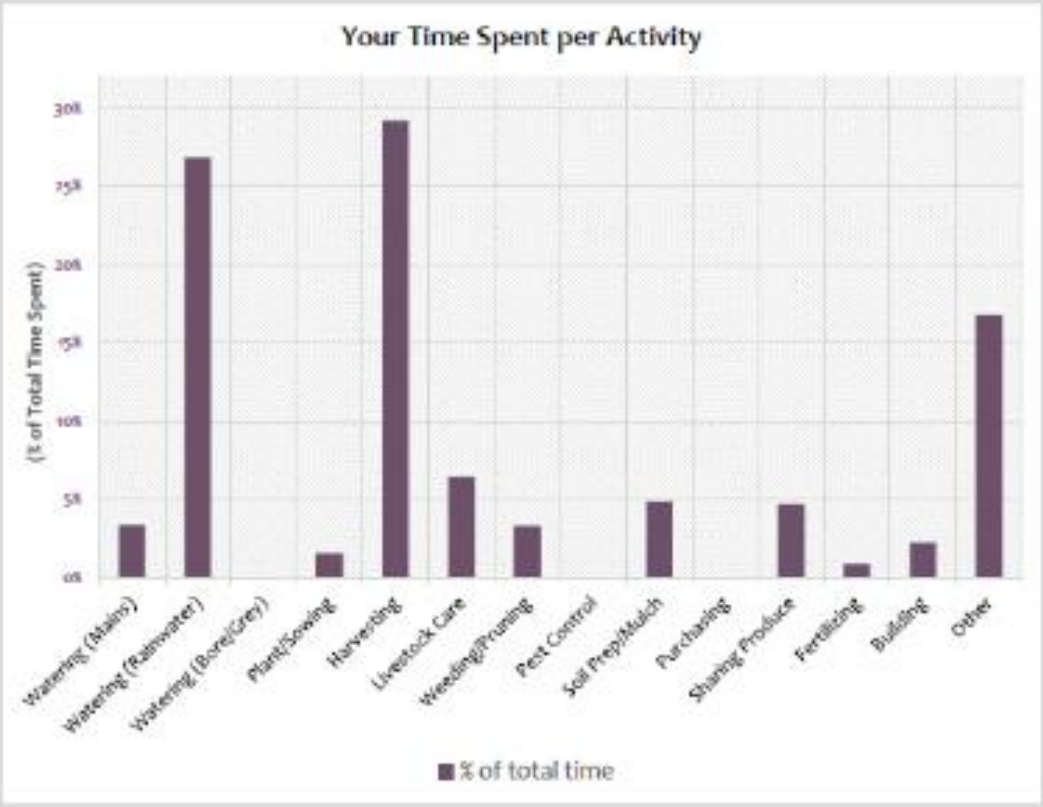
Your garden produced:

3-9 kg of food

Worth $40 (based on data gathered at 2 SA supermarkets). Or if you compare it to the cost of certified organic supermarket produce: $89 (an increase of 220% in value).

Your produce contains 8920 kJ of energy

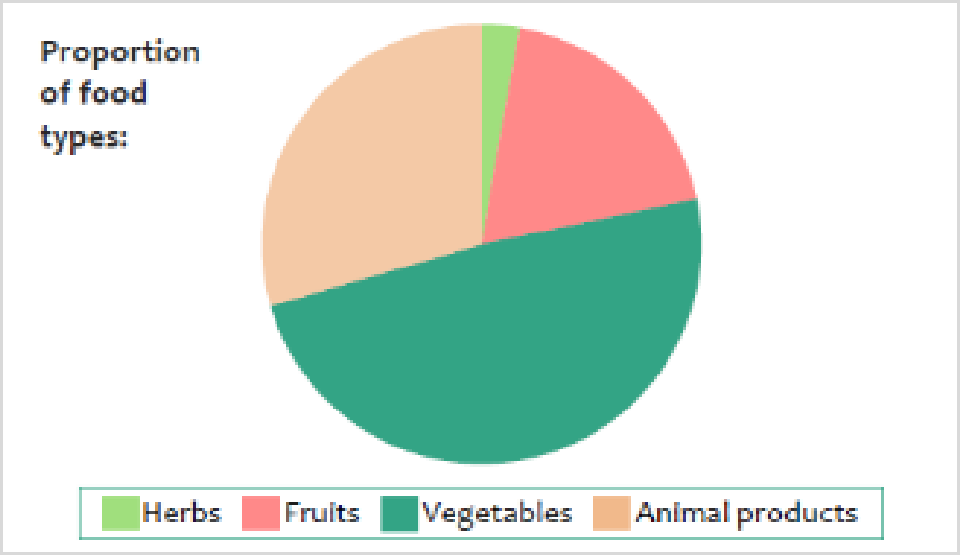
In addition to 160 grams of protein



Most of your time was spent on Harvesting, Watering (Rainwater) and Other.

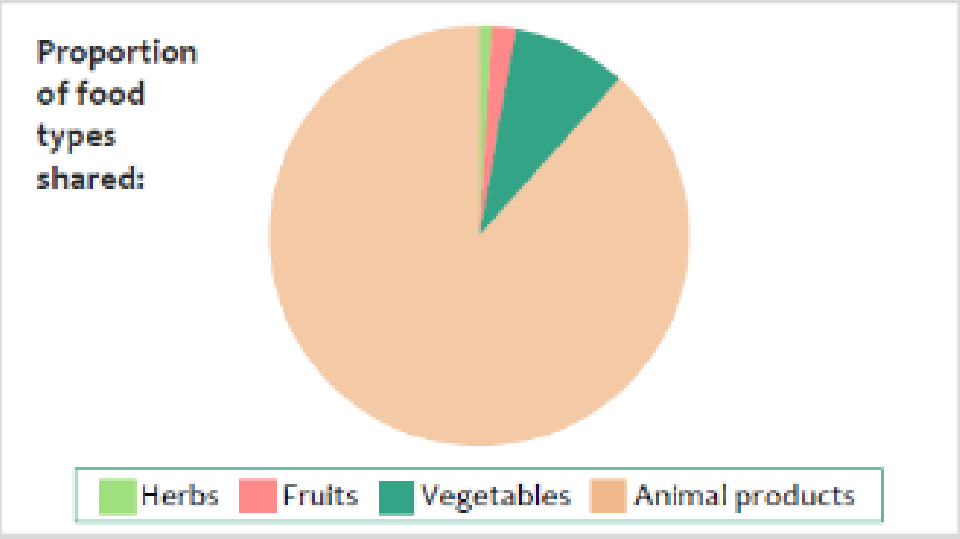
What did you grow?

Of the 510.4kg you produced, your harvest was mostly made up of Vegetables and Animal products.



What did you share?

Of the **510.4** kg you harvested, you shared **114.0** kg with others.
That's **22%** of your total harvest



You gave the most food away to **family**

Notes

- In South Australia, **residential mains water** is priced in 3 tiers (Visit www.sawater.com.au to learn more). We used the middle Tier 2 price for water to calculate any cost of mains water used on your food garden. Of course depending on your household water usage, the actual cost may be slightly different.

- The **retail certified organic prices** were estimated using the overall average price difference (220%) from 2 SA supermarkets in May 2018. In Australia, supermarkets remain the major outlets for organic shopping (Google "Australian Organic Market Report 2017" to learn more about organics in Australia).

- For **unusual crops**, when no supermarket retail prices could be found, subsitutions with similar crops were made. For example, unsual tropical fruits were priced as "bananas" and unusual salad greens were priced as "greens" (a combined average price of other greens).

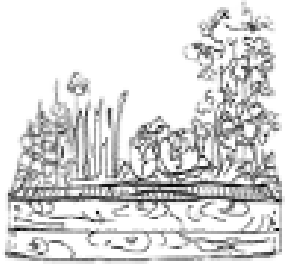
- All the **nutritional information** (energy and protein) came from the NUTTAB Online Database (Google "NUTTAB Database" to look up additional nutritional information about all kinds of foods).

In total you entered 1958 data entries!

This is by far the greatest number of data entries by a single person - an incredible effort. Thank you :)

Your Area # 1 Raised Bed/s Results

Total Production



In total this Raised bed area produced:

247 kg of food

Worth **$3,228** (based on data gathered at 2 SA supermarkets). Or if you compare it to the cost of certified organic supermarket produce: **$7,101** (an increase of 220% in value).

Your produce contains **242757** kilojules (kJ) of energy (Average daily adult intake = 8,700kJ).

In addition to **3481** grams (g) of protein (Average daily protein = 45-60g for women and 65-80g for men).

Total Inputs

Your Raised bed area required:

12,281 litres of water

$16 In expenses (this may include your one-off costs, but not water costs).

114 hours to tend

Per m^2

Your area produced:

8.24 kg of food

Worth **$107.59** (based on data gathered at 2 SA supermarkets). Or if you compare it to the cost of certified organic supermarket produce: **$236.70** (an increase of 220% in value).

Containing **8092** kJ of energy

And with **116** grams of protein

Your Area # 2 Poultry: Chicken Results

Total Production



In total this chook area produced:

149.8 kg of food (roughly **2496** eggs)

Worth **$1,297** (based on data gathered at 2 SA supermarkets). Or if you compare it to the cost of certified organic supermarket produce (an increase of 220% in value): **$2,854**

Your produce contains **764840** kilojules (kJ) of energy (Average daily adult intake = 8,700kJ).

In addition to **16548** grams (g) of protein (Average daily protein = 45-60g for women and 65-80g for men).

Total Inputs

Your chook area required:

1576.9 litres of water

$221 in expenses (this may include your one-off costs, but not water costs).

84 hours to tend

Per m^2

Your area produced:

7.5 kg of food (roughly **125** eggs)

Worth **$64.87** (based on data gathered at 2 SA supermarkets). Or if you compare it to the cost of certified organic supermarket produce (an increase of 220% in value): **$142.71**

Containing **38242** kJ of energy

And with **827** grams of protein

Your Area # 3 In-ground Bed/s Results

Total Production



In total this In-ground bed area produced:

95 kg of food

Worth **$654** (based on data gathered at 2 SA supermarkets). Or if you compare it to the cost of certified organic supermarket produce (an increase of 220% in value): **$1,440**

Your produce contains **147615** kilojules (kJ) of energy (Average daily adult intake = 8,700kJ).

In addition to **746** grams (g) of protein (Average daily protein = 45-60g for women and 65-80g for men).

Total Inputs

Your In-ground bed area required:

18724.2 litres of water

$11 In expenses (this may include your one-off costs, but not water costs).

103 hours to tend

Per m^2

Your area produced:

1.19 kg of food

Worth **$8.18** (based on data gathered at 2 SA supermarkets). Or if you compare it to the cost of certified organic supermarket produce (an increase of 220% in value): **$17.99**

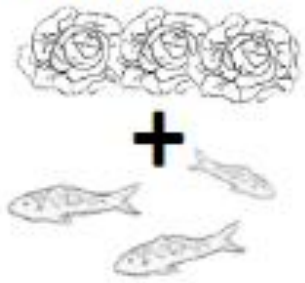
Containing **1845** kJ of energy

And with **9** grams of protein

Your Area # 4 Aquaponics Results

In total this aquaponics system produced:

Total Production



18.3 kg of food (**0.85** kg of fish and **17.5** kg of produce)

Worth **$125** (based on data gathered at 2 SA supermarkets). Or if you compare it to the cost of certified organic supermarket produce (an increase of 220% in value): **$274**

Your produce contains **13321** kilojules (kJ) of energy (Average daily adult intake = 8,700kJ).

In addition to **231** grams (g) of protein (Average daily protein = 45-60g for women and 65-80g for men).

Total Inputs

Your aquaponics system required:

1515.6 litres of water

$10 in expenses (this may include your one-off costs, but not water costs).

48 hours to tend

Per m^2

Your area produced:

18.35 kg of food

Worth **$124.75** (based on data gathered at 2 SA supermarkets). Or if you compare it to the cost of certified organic supermarket produce (an increase of 220% in value): $274.45

Containing **13321** kJ of energy

And with **231** grams of protein



Edible Gardens is a Discovery Circle project supported by:

Natural Resources
Adelaide and Mt Lofty Ranges

Government of South Australia
Department for Environment and Water

City of Salisbury

City of MARION

This research was also supported by an Australian Government Research Training Program (RTP) Scholarship

University of South Australia

Visit the Discovery Circle: www.discoverycircle.org.au

Appendix B Additional Work from Chapter 4

Published Supplementary Materials

The following are available online at www.mdpi.com/xxx/s1

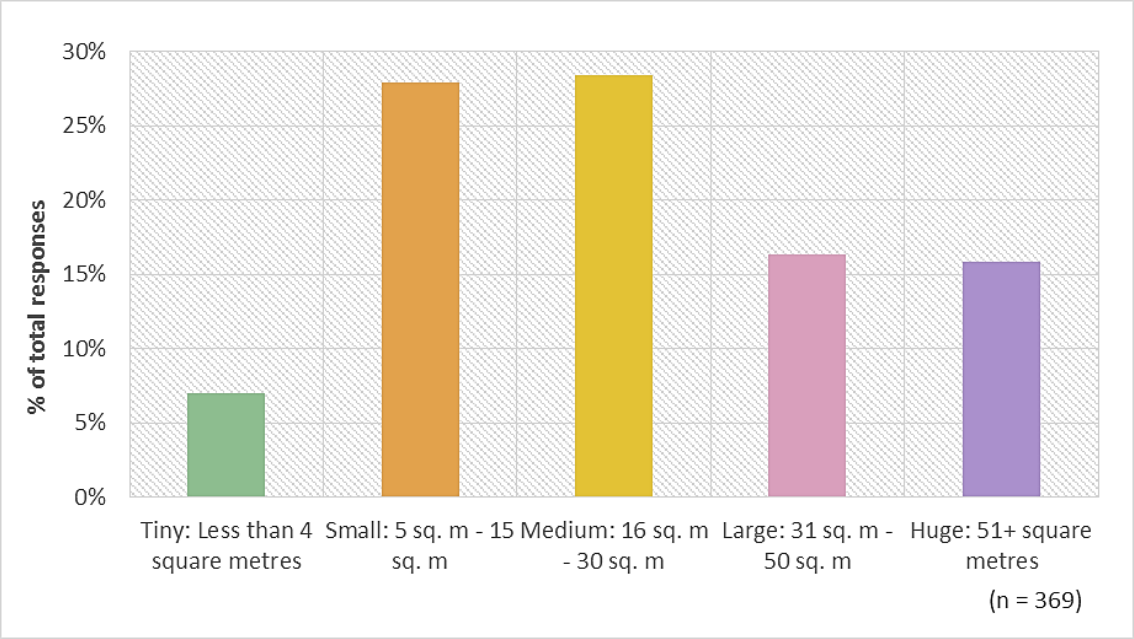


Figure S1: Total area under production reported by the EG survey respondents.

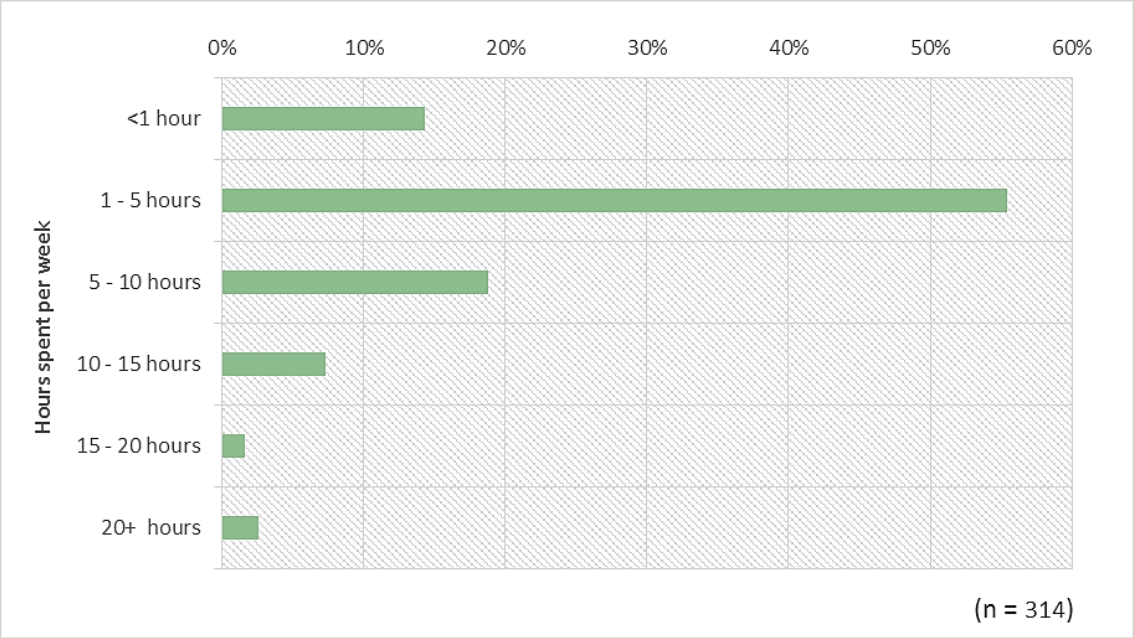


Figure S2: Estimated average time spent per week by the EG respondents on their food gardens.

Table S1: Comparison of the EG area under production categories with the square meter per person categories from Ward and Symons's (2017) optimized garden model.

Edible Gardens Area under production	**Category #**	**Count**	**% of total (333)**	**Comparable category from Ward & Symons (2017)**
Tiny: <4m²/person	1	79	21%	5m²/person
Small: 5-15m²/person	2	181	49%	10m²/person
Medium: 16-30m²/person	3	67	18%	20m²/person
Large: 31-50m²/person	4	4	1%	40m²/person
Huge: 51+m²/person	5	2	1%	80m²/person
No comparable area	0	0	0%	160m²/person

Full list of relevant survey questions referenced in chapter 4:

Supplementary material: Survey Questions from the "Edible Gardens" project

Category #1: Gardening background

1. Do you grow food at home, at a community garden, or at a school? (Please select the main place you grow food. If you grow food at more than one place you can complete the survey again)
[checkbox] At home
[checkbox] At a community garden
[checkbox] At a school

2. How long have you been growing food?
[Checkbox] Less than 1 year
[Checkbox] 1 - 5 years
[Checkbox] 6 - 10 years
[Checkbox] 11+ years

3. How would you describe your gardening consistency:
[Checkbox] On and off again
[Checkbox] Seasonal e.g. every summer
[Checkbox] All through the year.
[Checkbox] Other (please describe): [Blank line]

4. What kinds of approaches to food gardening to you use? (Please check all that apply and add any extras not listed)
[Checkbox] Conventional gardening (i.e. digging and tilling the soil)
[Checkbox] Make own compost
[Checkbox] Have a worm farm
[Checkbox] No-dig gardening
[Checkbox] Low use of chemical fertilisers and pesticides
[Checkbox] Organic
[Checkbox] Permaculture
[Checkbox] Companion planting
[Checkbox] Bio-dynamic
[Checkbox] Other (please describe): [Blank line]

5. What were the top three things that delayed or challenged you getting into food gardening?
1. [Blank line]
2. [Blank line]
3. [Blank line]

6. Is there currently anything that makes it difficult for you to continue growing food?
[Checkbox] No
[Checkbox] Yes, (please describe): [Blank line]

Category #2: Physical garden elements

7. How many different food producing areas do you have? For example, if you have a vegetable patch (1 area), some fruit trees (1 area) and some planter pots (1 area), then that's 3 areas in total. Or you might keep chickens in a poultry run (1 area), and have an aquaponics system (1 area), which makes 2 areas in total.

I have this many areas:
[Dropdown menu 1 – 20 areas]

8. What kinds of food producing areas do you have? (Please check all that apply):
[Checkbox] In ground bed/s
[Checkbox] Raised garden bed/s
[Checkbox] Pots or planters
[Checkbox] Fruit tree/s
[Checkbox] Vertical garden/s
[Checkbox] Poultry keeping - chickens
[Checkbox] Poultry keeping – other
[Checkbox] Aquaponics system
[Checkbox] Wicking beds
[Checkbox] Bee hive/s
[Checkbox] Other (please describe): [Blank line]

9. What is the approximate total size of all your food producing areas added together? An estimate is okay.
[Checkbox] Tiny: Less than 4 square metres
[Checkbox] Small: 5 sq. m – 15 sq. m.
[Checkbox] Medium: 16 sq. m – 30 sq. m.
[Checkbox] Large: 31 sq. m – 50 sq. m
[Checkbox] Huge: 50+ square metres

Category #3: Garden inputs

10. On average how much time, per week, do you spend tending your food producing areas?
[Blank line] hours per week

11. Please estimate the number of hours spent gardening per week by the various members of your household:
[Blank line] Women over 18 years
[Blank line] Men over 18 years
[Blank line] Children less than 18 years

12. From where is the water you use on your food-producing areas sourced? (Please check all that apply):
[Checkbox] Mains water
[Checkbox] Rain water
[Checkbox] Recycled water / blended water (Purple piping)
[Checkbox] Grey water
[Checkbox] Other

13. How do you usually apply the water? (Please check all that apply):
[Checkbox] Manual irrigation with a hose, watering can or bucket
[Checkbox] Drip irrigation system (surface or sub-surface)
[Checkbox] Sprinkler
[Checkbox] Wick sub-irrigation / wicking beds
[Checkbox] Animal water (any method of providing water for urban livestock)
[Checkbox] Other [Blank line]

14. What do you estimate was the total cost to set up these food-producing areas?
$ [Blank line]

15. What do you estimate is the average monthly cost of things you add to your food-producing areas? This includes seeds, seedlings, soil improvement, tools, feed for livestock, or garden membership fees if part of a community garden.
$ [Blank line]

16. The following statement is about something that may motivate you to grow and maintain a food garden. Please rate the statement according to how true it is for you. When answering please consider any food production in your garden (e.g. vegetables, fruits, herbs, chickens, fish or bees etc.)

"I produce food to save money"
[Checkbox] Strongly disagree
[Checkbox] Disagree
[Checkbox] Neutral
[Checkbox] Agree
[Checkbox] Strongly agree

17. Do you save money by growing some of your own food? An estimate is okay.
[Checkbox] Yes, over 75% of my weekly household fruit and vegetable budget
[Checkbox] Yes, between 26-75% of my weekly household fruit and vegetable budget
[Checkbox] Yes, between 6-25% of my weekly household fruit and vegetable budget
[Checkbox] Yes, 0-5% of my weekly household fruit and vegetable budget
[Checkbox] I think we break even
[Checkbox] Unsure
[Checkbox] No, I don't think I save money
[Checkbox] No, I know I don't save money
[Checkbox] Not applicable (School garden)

Category #4: Demographics

18. How old are you?
[Checkbox] 18 – 20
[Checkbox] 21 – 30
[Checkbox] 31 – 40
[Checkbox] 41 – 50
[Checkbox] 51 – 60
[Checkbox] 61 – 70
[Checkbox] 71 – 80
[Checkbox] 81+

19. Please select your gender.
[Checkbox] Male
[Checkbox] Female
[Checkbox] Indeterminate/Intersex/Unspecified

20. Are you currently renting or do you own your own home?
[Checkbox] Renting
[Checkbox] Own my own home / have a mortgage
[Checkbox] Other situation (please describe): [Blank line]

21. How many people are there in your household?
[Blank line]

22. How many of your household are of primary school age or younger?
[Blank line]

23. How many of your household are over 65 years of age?
[Blank line]

24. What is the highest level of education have you completed?
[Checkbox] School (Year 10)
[Checkbox] School (Year 11)
[Checkbox] School (Year 12)
[Checkbox] Diploma/Certificate
[Checkbox] Bachelor degree
[Checkbox] Postgraduate Degree
[Checkbox] Other (please specify)

25. What is the postcode of the suburb you live in?
[Blank line]

Appendix C Additional Work from Chapter 5

Published Supplementary Materials

The following are available online at www.mdpi.com/xxx/s1

Table S1: List of relevant survey questions used in the EG online survey.

Supplementary Material: Online Survey Questions from the "Edible Gardens" Project

Category #1: Background, motivations & learning sources

1. Do you grow food at home, at a community garden, or at a school? (Please select the main place you grow food. If you grow food at more than one place you can complete the survey again)
[checkbox] At home
[checkbox] At a community garden
[checkbox] At a school

2. How long have you been growing food?
[Checkbox] Less than 1 year
[Checkbox] 1 - 5 years
[Checkbox] 6 - 10 years
[Checkbox] 11+ years

3. How would you describe your gardening consistency:
[Checkbox] On and off again
[Checkbox] Seasonal e.g. every summer
[Checkbox] All through the year.
[Checkbox] Other (please describe): [Blank line]

4. Why did you start growing some of your own food?
[Blank line]

5. What are the top three reasons you now grow some of your own food?
1. [Blank line]
2. [Blank line]
3. [Blank line]

6. From where have you learnt about or received food gardening knowledge from? Please check all that apply.
[Checkbox] Family
[Checkbox] Friends
[Checkbox] Books
[Checkbox] Online
[Checkbox] From attending classes or courses
[Checkbox] From other home gardeners
[Checkbox] From other community gardeners
[Checkbox] Trial and error
[Checkbox] Other (please describe): [Blank line]

Category #2: Food preservation

7. To what extent to you agree with this statement? Please select one of the following:

"I experience gluts of crops (a lot of one crop) when growing food".
[Checkbox] Strongly disagree
[Checkbox] Disagree
[Checkbox] Neutral
[Checkbox] Agree

[Checkbox] Strongly agree

8. Please select all the food processing, storing, or preserving techniques you used within the last 12 months:
[Checkbox] Storing produce
[Checkbox] Drying or de-hydrating produce
[Checkbox] Freezing produce
[Checkbox] Canning
[Checkbox] Making jams or preserves or sauces
[Checkbox] Pickling or fermenting produce
[Checkbox] Other (please describe): [Blank line]

9. If you don't process, store of preserve food, is there any particular reason why not?
[Blank line]

10. If you do process, store of preserve food, why do you?
[Blank line]

Category #3: Food distribution

11. Do you gift, share or donate food you grow to others outside you household?
[Checkbox] Yes
[Checkbox] No

12. If "yes", how often do you share, gift or donate food to others?
[Checkbox] Once or twice a year
[Checkbox] Every couple of months
[Checkbox] Every couple of weeks
[Checkbox] Every time I harvest something

13. If you don't gift, share or donate food to others outside of your household, is there any particular reason why not?
[Blank line]

14. If "yes", who have you given food to? Please check all that apply:
[Checkbox] Family
[Checkbox] Friends
[Checkbox] Neighbours
[Checkbox] Strangers
[Checkbox] Work
[Checkbox] Swap meet
[Checkbox] Charities, for example, Oz Harvest
[Checkbox] Other (please describe): [Blank line]

15. If "yes", do you purposefully grow extra food to give, share or donate to others?
[Checkbox] Yes
[Checkbox] No

Category #4: Social Capital

16. Please rate the following statements out of five, where 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree and 5 = Strongly Agree:

"People around this neighbourhood are willing to help their neighbours."
"This is a close-knit, or "tight" neighbourhood where people generally know one another."
"If I had to borrow $30 in an emergency, I could borrow it from a neighbour."
"People in this neighbourhood generally get along with each other."
"People in this neighbourhood can be trusted."
"If I were sick, I could count on my neighbours to shop for groceries for me."
"People in this neighbourhood share the same values."

17. How long have you lived in your house/home?
[Blank line]

18. How long have you lived in your neighbourhood?
[Blank line]

19. Have you ever organised or participated in group gardening activities? For example, working bees, garden tours, or harvest parties.
[Checkbox] Yes, I have organised events.
[Checkbox] Yes, I have participated in these types of activities.
[Checkbox] No, I have not organised or participated in these types of activities.

20. If you answered 'yes' to the above question, what kind of activities have you organised or participated in?
[Blank line]

Category #5: Demographics

21. How old are you?
[Checkbox] 18 – 20
[Checkbox] 21 – 30
[Checkbox] 31 – 40
[Checkbox] 41 – 50
[Checkbox] 51 – 60
[Checkbox] 61 – 70
[Checkbox] 71 – 80
[Checkbox] 81+

22. Please select your gender.
[Checkbox] Male
[Checkbox] Female
[Checkbox] Indeterminate/Intersex/Unspecified

23. Are you currently renting or do you own your own home?
[Checkbox] Renting
[Checkbox] Own my own home / have a mortgage
[Checkbox] Other situation (please describe): [Blank line]

24. How many people are there in your household?
[Blank line]

25. How many of your household are of primary school age or younger?
[Blank line]

26. How many of your household are over 65 years of age?
[Blank line]

27. What is the highest level of education have you completed?
[Checkbox] School (Year 10)
[Checkbox] School (Year 11)
[Checkbox] School (Year 12)
[Checkbox] Diploma/Certificate
[Checkbox] Bachelor degree
[Checkbox] Postgraduate Degree
[Checkbox] Other (please specify)

28. What is the postcode of the suburb you live in?
[Blank line]

Table S2: List of REP items used in the EG project online survey

Supplementary Material: List of REP-style scale items from the "Edible Gardens" Project

Category #6: Recreation Experience Preference-Style Scale Values

The following statements are about things that motivate you to grow and maintain a food garden. Please rate each statement according to how true it is for you, where 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree and 5 = Strongly Agree.

When answering these questions please take into account any food production in your gardens (e.g. vegetables, fruits, herbs, chickens, fish or bees etc.)

1. I produce food to save money
2. I produce food to have fresh produce
3. I produce food to have produce that is healthy for me
4. I produce food to have tastier food
5. I produce food because I enjoy it
6. I produce food to keep physically fit
7. I produce food to relax physically
8. I produce food to feel a sense of pride
9. I produce food to prove to myself and others that I can produce my own food
10. I produce food to feel independent
11. I produce food to spend time with family
12. I produce food to be with other food producers
13. I produce food to meet new and varied people
14. I produce food to develop my skills
15. I produce food to learn new things
16. I produce food to enjoy the sounds and smells of nature
17. I produce food to be close to nature
18. I produce food to be creative
19. I produce food to remind me about the good times I've had in the past
20. I produce food to help release tension
21. When I garden, my mind moves at a slower pace
22. I produce food to get away from the usual demands of life
23. I produce food to experience tranquillity
24. I produce food to be alone
25. I produce food to be near considerate people
26. I produce food to be away from the family for a while
27. I produce food so I can share what I have learned with others
28. Food production is an important part of who I am
29. I use food production as a time to reflect
30. I produce food to grow and develop spiritually

Appendix D Additional Work from Chapter 6

Supplementary Materials

These materials are supplementary materials for the paper in Chapter 6 which is intended to be submitted the same day as this thesis.

Supplementary Table 1. A summary of the combined total results from the Edible Gardens project

No. of gardens		34				
No. of garden areas		93				
Tech-crop categories		aqua-fivg; bee-hon; bed-orch; other-orch; pot-orch; bed-veg/vegh/herb/other; pot-veg/vegh/herb/other; chkn-egg; poult-egg; raised-veg/vegh/herb; bed-vine; wick-veg/vegh/herb				
Water sources		Mains water, rainwater and bore / grey water				
Irrigation methods		Manual (watering can, bucket, sprinkler or hose), drip/spray irrigation lines, automatic irrigation systems or 'other'.				
			Total	**Min / Max**	**Median / Average**	
Duration of data collection		days	7565 (equivalent to 252 months!)	23 / 880	176 / 225	
Inputs	Area under production	m^2	3,520.9	4 / 731	49 / 98	**Per m2**
	Estimated setup costs *survey data	$AUS	$70,195	$0 / $10,000	$1,000 / $2,005	$19.94
	Ongoing costs	$AUS	$6,735.72	$0 / $1,787.50	$98.89 / $198.11	$2.13
	Time	hours	144,582	82 / 36,657	1,832 / 4,016	41 hours
	Applied Irrigation	kL	690.8	0.2 / 163.4	5.9 / 19.2	218L
	Recorded Rainfall	kL	1231.4	0.16 / 414.3	9.8 / 37.3	389L
Outputs	Total yield	kg	3,479	2 / 682	32 / 102	1.10kg
	Inherent energy	kJ	5,736,153	1,896 / 1,150,830	69,117 / 168,710	1815 kJ
	Inherent protein	g	77,420	35 / 21,005	986 / 2,895	30 g protein
	Retail value	$AUS	$28,075.61	$38.76 / $5,433.41	$341.83 / $825.75	$8.88
	WUE_{gross}	kg/kL	-	0.14 / 10.69	2.50 / 3.07	-
	WUE_{nut}	kJ/kL	-	132 / 12,486	4,400 / 4,583	-
	WUE_{fin}	AUS$/kL	-	1.83 / 77.48	23.84 / 27.37	-
Retail value of shared food		$AUS	$4,246.62	$1.10 / $1,144.68	$27.40 / $157.28	-
Recipients of shared food		Family; friends; community; swap meet; other				

Supplementary Table 2. A complete list of reported crops and their harvest weights during the Edible Gardens project. The list is divided by crop category.

	Crop Name	Total harvest weight (kg)		Crop Name	Total harvest weight (kg)
Fruits and Nuts	Apple (All kinds)	128.6	Vegetables	Artichoke	0.5
	Apricot	71.0		Asparagus	13.1
	Bananas	27.3		Bean, Green	47.0
	Berries (Mixed or undefined)	0.2		Beetroot	25.8
	Blackberry	0.4		Bok choi or Pak choi	7.0
	Blueberry	0.9		Broad bean	24.0
	Cherry	0.6		Broccoli	35.5
	Fig	31.9		Brussel sprouts	2.4
	Fruit (Mixed or undefined)	9.7		Cabbage	2.0
	Grapefruit	25.1		Cabbage, Chinese	19.3
	Grapes (Green, red and other)	12.6		Capsicum (Red and green)	48.3
	Lemon	56.8		Carrot	140.9
	Lime	3.7		Cauliflower	2.7
	Loquat	0.6		Celery	5.7
	Macadamias	0.2		Chillies	12.3
	Mandarin, imperial	8.7		Cucumber (All kinds)	121.3
	Melon, rockmelon	19.2		Eggplant	56.5
	Melon, watermelon	7.8		Fennel	0.6
	Mulberries	25.9		Garlic	20.1
	Nectarine	71.4		Greens (Mixed or undefined)	16.7
	Orange (All kinds)	96.1		Jalapeno	0.8
	Passionfruit	0.2		Kale	6.8
	Peach	93.0		Leek	5.1
	Pear (All kinds)	135.9		Lettuce (All kinds)	30.7
	Pepino	0.3		Olives	1.6
	Plum	36.8		Onion (All kinds)	51.1
	Pomegranate	3.8		Parsnip	11.1
	Quince	25.9		Peas	7.6
	Raspberry	0.3		Potato (All kinds)	65.1
	Rhubarb, stalk	31.5		Pumpkin (All kinds)	193.0
	Strawberry	30.8		Radishes	3.7
Herbs	Basil	10.9		Rainbow chard	2.2
	Bay leaves	0.1		Rocket	1.9
	Chives	0.6		Silverbeet	14.8
	Coriander	2.4		Snow peas	1.2
	Dill	0.3		Spring onion	9.0
	Herbs (Mixed or undefined)	5.4		Spinach, english	52.3
	Mint (All kinds)	2.5		Sprouts	0.1
	Oregano	1.2		Sweet corn	55.0
	Parsley	11.5		Sweet potato	2.8
	Rosemary	0.5		Tomato (All kinds)	419.1
	Tarragon	0.2		Turnip	1.1

	Thyme	0.6		Vegetables (Mixed or undefined)	48.0
Animal Products	Eggs, chicken	413.7		Zucchini	343.9
	Eggs, duck	7.6			
	Fish, silver perch	0.9			
	Honey	4.3			
	Honeycomb	0.5			
Total harvested weight:			3349.5 kg		

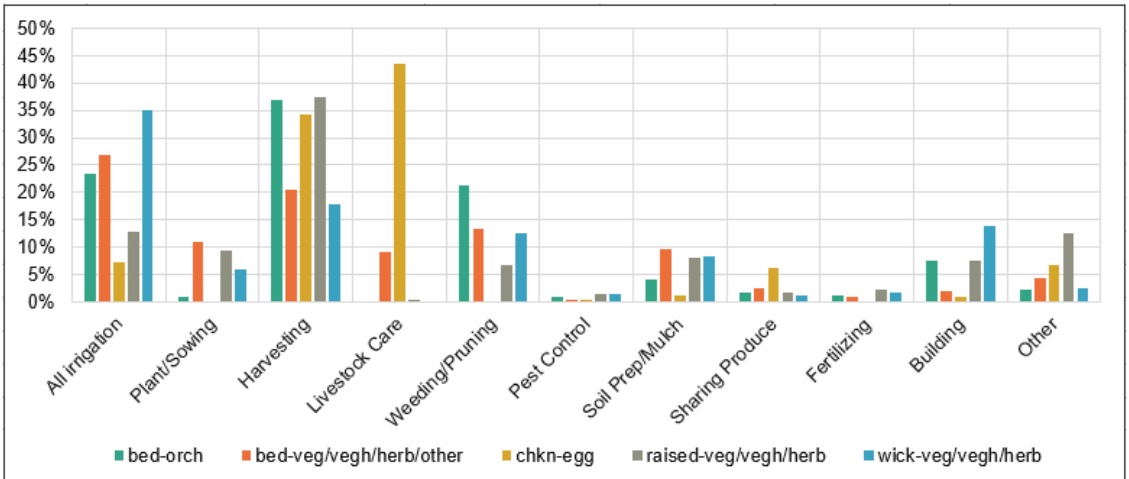
Supplementary Table 3. An overview of the five main tech-crop categories of the EG project.

Tech-crop name	**Acronym**	**Count of areas**	**Count of data entries**	**Total area (m^2)**	**Median area (m^2)**
In-ground bed – fruit from an orchard (fruit trees)	Bed-orch	20	552	1709	12
In-ground bed – vegetables/ vegetables and herbs / herbs / other	Bed-veg/vegh/herb/ other	21	1648	553	15
Chicken run – eggs	Chkn-egg	15	2261	392	10
Raised bed – vegetables/ vegetables and herbs / herbs/other	Raised-veg/vegh/herb	17	2380	288	12
Wicking bed – vegetables, vegetables and herbs / herbs/other	Wick-veg/vegh/herb	9	938	82.0	5

Supplementary Table 4. The labour invested in each garden activity per square metre per 30 days for the five main tech-crop categories.

Activity	**Bed-orch**	**Bed-veg/vegh /herb/other**	**Chkn-egg**	**Raised-veg/vegh/herb**	**Wick-veg/vegh/herb**
Watering (Mains)	0.18	0.08	0.08	0.17	0.17
Watering (Rainwater)	0.25	0.08	0.19	0.20	0.25
Watering (Bore/Grey)	0.17	0.17	-	0.08	-
Plant/Sowing	0.38	0.50	-	0.50	0.50
Harvesting	0.08	0.08	0.08	0.08	0.03
Livestock Care	-	-	0.17	-	-
Weeding/Pruning	1.26	0.50	-	0.33	0.33
Pest Control	0.42	0.25	0.21	1.00	0.33
Soil Prep/Mulch	0.42	0.83	4.00	0.75	0.75

Sharing Produce	0.08	0.17	0.17	0.08	0.08
Fertilizing	1.04	0.29	-	0.33	0.10
Building	1.25	0.33	0.42	2.00	2.00
Other	1.00	0.33	0.17	0.96	0.50



Frequency of main food garden activities

	Tech-crop categories	Daily	Weekly	Every 3 weeks	Every 2 months
Irrigation	Bed-orch	23.1%	39.8%	33.3%	3.7%
	Bed-veg/vegh/herb/other	45.6%	30.6%	11.9%	11.9%
	Chkn-egg	30.5%	34.4%	18.8%	16.4%
	Raised-veg/vegh/herb	49.8%	39.6%	8.7%	2.0%
	Wick-veg/vegh/herb	23.2%	43.4%	29.8%	3.5%
Harvesting	Bed-orch	60.0%	27.3%	8.5%	4.2%
	Bed-veg/vegh/herb/other	59.3%	31.7%	7.0%	2.0%
	Chkn-egg	58.3%	27.1%	10.8%	3.7%
	Raised-veg/vegh/herb	54.6%	32.2%	8.7%	4.5%
	Wick-veg/vegh/herb	59.1%	32.7%	6.8%	1.4%

Supplementary Figure 1. A comparison of the percentages of total time spent on different garden-related activities by the five main tech-crop categories, and the frequency of the two dominant activities – irrigation and harvesting.

Supplementary Table 5 A breakdown of the calculated setup costs for each tech-crop category, including details and assumptions.

	Tech-crop category: Bed-orch
Details	The combined average setup cost for bed-orch areas was $22.73 per square metre, as based on participant costing (Average of $23.58/m^2) and the calculated retail cost of parts at $18.50/m^2.
Assump.	For the retail cost it was assumed that there would be one young fruit tree ($35 - $70 each) planted per 4m^2, with two bags of soil or compost ($5 - $13 per bag) to plant each tree, and some mulch around the base (1/4 of bale of peastraw per tree at $10 - $17 per bale). Potential range per square metre: $11.90 - $25.10 (average of $18.50).
	Tech-crop category: Bed-veg/vegh/herb/other
Details	The combined average setup cost for bed-veg/vegh/herb/other areas was $18.91 per square metre, as based on participant costing (Average of $18.48/m^2) and the calculated retail cost of parts at $19.75/m^2.
Assump.	For the retail cost it was assumed that per square metre 2 – 3 punnets of vegetable and/or herb seedlings can fit ($2.50 - $5.50 per punnet) and adding at least one bag of compost or good soil ($5 - $13 per bag). Any additional mulch, stakes, fertiliser, or growing from seed instead of seedlings is not accounted for.
	Tech-crop category: Chkn-egg
Details	The combined average setup cost for chkn-egg areas was $121.46 per square metre, as based on participant costing (Average of $135.20/m^2) and the calculated retail cost of parts at $52.75/m^2.
Assump.	The retail cost assumed a median sized chicken run of 10m^2 (as based on EG data). The cost of a (relatively simple) chicken coop ($239 - $400), with one able of hay to fill it ($8.95), a feeder and water dripper ($40 - $90 for both), one bag of food to start ($19 - $27 per bag), shell-grit ($14 per bag) and at least two rolls of chicken wire ($18.48 each). Also assumes at least three hens ($20 each). Total range per m^2: $41.80 - $63.70 (average of $52.75).
	Tech-crop category: Raised-veg/vegh/herb/other
Details	The combined average setup cost for raised-veg/vegh/herb areas was $106.09 per square metre, as based on participant costing (Average of $107.84/m^2) and the calculated retail cost of parts at $99.10/m^2.
Assump.	The retail cost assumed raised bed frames ($44.97 - $385) filled with compost or soil ($30 - $192), with two punnets of vegetable or herb seedlings per square metre ($2.50 - $5.50 per punnet). Total range per m^2: $54.60 - $143.60 (average of $99.10).
	Tech-crop category: Wick-veg/vegh/herb/other
Details	The combined average setup cost for wick-veg/vegh/herb areas was $222.82 per square metre, as based on participant costing (Average of $209.04/m^2) and the calculated retail cost of parts at $291.70/m^2.
Assump.	The retail cost was based on publicly available instructions for building wicking beds as guided by the professional Australian gardener Costa (Link: https://www.sbs.com.au/shows/costa/listings/detail/i/1/article/6172/Wicking-Garden-Beds). The total reported cost to build the wicking bed and plant it out was $875, making the per square metre cost $291.70.

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