Introduction

Urbanization significantly alters soil and hydrological systems, their functioning, and the ecosystem services that they provide in cityscapes (Effland and Pouyat 1997; Shuster et al. 2005; Pickett and Cadenasso 2009). Urban soils often differ from undisturbed natural or agricultural soils, and can be characterized by low organic matter content, high levels of compaction, and the presence of physical and chemical contaminants (Pouyat et al. 2010). These biophysical properties of urban soils are challenging for people converting urban land for agricultural purposes due to poor soil structure (impeding crop growth), heavy metal contamination (hindering safe food cultivation), low nutrient content, and poor water retention (demanding more resources) (Beniston and Lal 2012). Urban agriculture is providing substantial food and health benefits to urban neighborhoods (Algert et al. 2014), especially in under-served communities with high barriers to fresh food access (Armstrong 2000). Thus, there is a growing need to understand how to manage urban agricultural soils for ecosystem services like food production and resource conservation (Santo et al. 2016).

In order to increase urban agricultural soil functioning, urban planners and urban gardeners are faced with the task of remediating soil degradation (Schwarz et al. 2016), building up soil fertility, and increasing soil water holding capacity (Surls et al. 2014) through soil management. In urban and rural agroecosystems alike, soil functioning is the ability of soils to conduct ecological and hydrological processes like nutrient cycling, decomposition, and water cycling (Karlen et al. 1997; Arshad and Martin 2002). There are multiple issues associated with accessing resources that facilitate soil functioning and ecosystem service generation. While environmental factors (e.g., climatic) can challenge urban agricultural soil and water management (Barthel and Isendahl 2013), social and political characteristics of urban landscapes can influence management implementation and effectiveness (Cohen and Reynolds 2014). Gardener-to-gardener interactions can influence management efficacy, soil fertility management, and irrigation methods (Saldivar-Tanaka and Krasny 2004; Kim et al. 2014). Wavering political support for urban agriculture projects in favor of urban development may lead to garden ephemerality (Schmelzkopf 2002; McClintock 2014) and thereby the continuous loss of soil improvement investment. Urban land-use planning and resource availability (e.g., water, soil, and tools) can lead to...
inequitable resource access, forcing communities to garden with poor infrastructure, limited access to uncontaminated soil and compost, and insufficient or expensive water (Wakefield et al. 2007).

Soil amendments (e.g., compost, fertilizer, manures) and groundcover management (e.g., mulching) can increase soil organic matter development, and boost soil moisture and water conservation in urban systems (Edmondson et al. 2014) to provide strategies through which gardeners may increase soil functioning (Beniston and Lal 2012). However, gardeners may lack access to these amendments due to financial or transportation barriers (Cohen and Reynolds 2014), and this is more often the case for gardeners in socially disadvantaged communities (Reynolds and Cohen 2016). This suggests that socio-demographic characteristics of gardeners and their neighborhoods may influence the ability of gardeners to manage their soils, and thus manage soil-based ecosystem services derived from high functioning soils.

In this study, we conducted research in urban community gardens in the California central coast, a landscape of biophysical complexity as well as historical and present day urban population growth, great human diversity, and socio-economic inequality (McWilliams 1999). We investigated how garden soil biophysical properties (soil structure, nutrients, and water holding capacity) that are indicators of urban soil functioning (Schindelbeck et al. 2008) vary with socio-demographic characteristics of the neighborhoods in which the gardens are embedded, and how relationships among soil properties and socio-demographics may affect soil-based ecosystem service provisioning. Specifically, we ask: (1) What are the biophysical properties of urban garden soils and do they correlate with garden groundcover management? (2) Do socio-demographic characteristics of garden neighborhoods correlate with biophysical properties of urban garden soils and groundcover management?

Materials and methods

Study system

We selected 25 urban community gardens in California for our research in three counties: Monterey (36.2400° N, 121.3100° W), Santa Clara (37.3600° N, 121.9700° W), and Santa Cruz (37.0300° N, 122.0100° W) (Figure 1; Table A1 in Appendix). The gardens represent a gradient in biophysical landscape heterogeneity, where varying mixes of natural, agricultural, open green space, and urban land-uses comprise and surround each urban center. The gardens also represent a gradient in microclimate as a result of the mountainous landscape, proximity to the coast, and different parent material or basic soil type. The parent soil type (texture) is primarily sandy loam, loamy sand, or loam (NRCS 2009) with a few gardens being in areas dominated by clay loam, clay, or silt loam (Table A1 in Appendix).

The neighborhoods around the selected gardens also vary in socio-economic and socio-demographic composition due to differences in the history of urbanization and demographic change. Santa Cruz and Monterey Counties – considered a salad bowl of the

![Figure 1](image-url). Locations of the 25 urban community gardens sampled in the California central coast from San Jose to Monterey.
USA – are leaders in the production of strawberries and leafy greens. Yet, many of the workers that pick these fruits and vegetables live in food insecure neighborhoods (Brown and Getz 2011). This has made community gardening, and the access to cultivable land, an appealing opportunity to increase food security, nutrition, and justice in the region (e.g., Mesa Verde Gardens, Watsonville, CA; http://www.mesaverdegardens.org/). In addition, the south part of the Monterey Bay has a history of a prosperous maritime industry, tourism, and the build-up of the US Pacific Naval forces in the Second World War – all of which have brought a diversity of people, employment opportunities, and both economic influence and hardship to the region (Norkunas 1993). Santa Clara County has experienced a rapid change to the biophysical and social landscape. The influx of Silicon Valley technology wealth has transformed the ‘Valley of Heart’s Delight’ – a once predominant orchard landscape tended to by Asian and European immigrants – into a paved over concrete landscape of uneven urban development and social inequality (Pellow and Park 2002). In San Jose, the city community gardening program supports over a thousand urban gardeners (San Jose Parks, Recreation & Neighborhood Services 2017), many of whom use gardens as an opportunity to grow a range of ethnic foods unavailable at the supermarket.

In sum, the 25 gardens in this study provide a system to assess how changes in social characteristics (demographics, economics) strongly influence the biophysical properties of gardens – here, soils. The study took place from May to September 2016 during which time the region was experiencing a fourth year of drought conditions. More than 80% of land cover within the three studied counties was classified under drought (Rippey 2016) and there were statewide water restrictions in place. To note, garden bylaws for some gardens had influenced or required gardens to impose watering restrictions, limiting the days of the week and time of day that gardeners were allowed to water (e.g., Community Gardens Program 2016).

**Urban garden soils**

In this study, we aimed to assess garden soil functions associated with regulating ecosystem services (e.g., nutrient cycling, decomposition, hydrologic cycling) (Karlen et al. 1997), by selecting abiotic and biotic indicators of ecological and hydrological processes and functions (Schindelbeck et al. 2008). We considered high functioning urban agricultural soils to have high organic matter, low bulk density, high soil nutrient contents, and high water holding capacity. Over the growing season (May to September 2016), we measured: (a) soil organic matter (SOM), (b) bulk density (BD) (g/cm³), (c) soil nutrient content (% Wt C, N, C:N Ratio), (d) water holding capacity (WHC), and (e) groundcover management. We established a 20 × 20 m grid at the center of each garden within which we took monthly soil and groundcover measurements on the following days: May 24–June 7, July 25–28, August 22–26 and September 16–19, 2016. We placed a total of eight, 1 × 1 m sub-plots, four out of which we randomly took soil measurements. If two random sub-plot locations fell within a garden plot managed by a single gardener, we selected a different sub-plot so that measurements were within a different gardener’s plot.

We followed Wilke’s (2005) standardized methods for all soil property measurements. To determine SOM, we took soil using metal augers (15–20 cm depth) in May and September and used the Loss on Ignition (LOI) method (500°C, 4 h) with dried soils to calculate the percent SOM. To determine BD, we used the core method to take soil with a cylindrical metal sampler in May, July and September. We weighed fresh soil, dried samples at 105°C, for 24 h, and then calculated BD with the final dried weight. We measured BD instead of soil texture because soils were intensively managed (meaning parent material was less relevant) and BD is a comparable indicator of soil structure and function in urban garden systems (Edmondson et al. 2014). To determine soil nutrient content, we collected soils with metal augers (15–20 cm depth) in May and August and sieved 2 mm of field fresh soil, dried soils for 24 h, ground and homogenized soils to be analyzed for C, N, and C:N ratio (UCSC Stable Isotope Laboratory, Santa Cruz, CA). To determine soil WHC, we took soil measurements in September using the bulk density core method following Wilke (2005). This is a standardized method that determines the maximum amount of water retained by the soil against gravity by saturating soil samples, draining soils of free water, and evaluating only the water held by the soil. We chose this method to standardize soil structure, as garden soils are continuously tilled and amended with purchased soil (e.g., potting soil) to disrupt soil aggregation. While this method uses sieved soil, which impacts soil structure, because of frequent tillage there is little time for macro-aggregates (>2 mm) to form in garden soils. We filled 2 × 2” cylinders with a perforated base with sieved, fresh soil, and placed them in a water bath overnight. We then capped and placed cylinders on a tray of sand for approximately 6 h, allowing soils to drain, and then removed and dried soils (105°C, 24 h) to calculate WHC. To assess groundcover management, we measured the groundcover composition within all eight 1 × 1 m sub-plots each month and calculated the percent cover of bare soil, herbaceous vegetation, rock, leaf litter, and mulch (including woodchips, straw, and other types of mulch cover). We also
counted the number of herbaceous plant species (including crops, weeds, and ornamental plants) in the sub-plots as a potential covariate that could affect soil properties because plant diversity is associated with nutrient cycling and soil fertility in agroecosystems (Altieri 1999; McDaniel et al. 2014).

In addition, further information was collected on soil and groundcover management through another project on water use. A subset of urban gardeners (26) across the study sites participated in a water use study in July and September 2016 (please see Lin et al. (2018) for more information). As part of the study, gardeners were given a survey primarily to understand water use, but questions on soil management (i.e., the use and type of soil amendments) were included. This information has been brought into the present analysis to help establish the role of soil amendments in establishing soil parameters.

**Socio-demographic information**

We collected socio-demographic information for the neighborhood census tracts surrounding gardens (all gardens were situated within a single census tract) from the Regional Opportunity Index (ROI) (Center for Regional Change 2015). The ROI uses data from the American Community Survey (US Census Bureau 2014) to construct people and place indices, each comprised of multiple domains calculated from two or more indicators that describe relative assets in education, the economy, housing, mobility/transportation, health/environment, and civic life (Table 1). We used domain, rather than index or indicator values for our analysis as they represent a finer scale at which to look at socio-demographic and economic characteristics of neighborhood populations and areas that may affect garden properties. We first ran a Pearson’s Correlation Analysis and calculated variation inflation factor (VIF) scores for all domains to examine for collinearity (Table A1 in Appendix). Then, we selected five non-correlated domains (taken at 5% level significance level and ≤3 VIF) that capture a range of socio-demographic characteristics that may drive soil properties: education (from people index), housing (from people index), mobility (from people index), housing (from place index), and health/environment (from place index).

**Statistical analysis**

We used generalized linear regression and a model selection approach based on Akaike’s information criterion (AIC) to determine what groundcover characteristics are strong predictors of soil properties. Initial analyses confirmed that soil properties and groundcover characteristics did not differ across months, and so we used mean values for each site across all sampling periods. We included percent mulch, grass, rocks (arcsin

---

**Table 1. Regional Opportunity Index domains, their indicators, and minimum, maximum, and mean values across the 25 sites.**

| Opportunity Index | Domain | Indicators | Min | Max | Mean |
|-------------------|--------|------------|-----|-----|------|
| People            | Education | College Educated Adults (%), Math Proficiency (%), Employment Rate (%) | 30.5 | 61.2 | 47.5 |
|                   | Health/environment | Infant Health (%), Years of Life Lost Rate, Prenatal Care (%), Health Care Availability (#) | 6.7 | 78.5 | 39.2 |
|                   | Civile | Education | 49.7 | 88.1 | 66.1 |
|                   | Economy | Employment Rate (%) | 44.7 | 78.4 | 59.4 |
|                   | Housing | Housing Affordability (%), Housing Adequacy (%) | 6.7 | 78.5 | 39.2 |
|                   | Mobility/transportation | Infant Health (%), Infant Mortality Rate (%), Years of Life Lost Rate, Infant Mortality Rate (%) | 6.7 | 78.5 | 39.2 |
|                   | Civic Life | Employment Rate (%) | 44.7 | 78.4 | 59.4 |

VIF: variation inflation factor; ROI: Regional Opportunity Index.
transformed), and leaf litter (arcsin transformed) as non-correlated explanatory variables in a model for each soil property (n = 7 models), and included the number of herbaceous plant species as a covariate. We used the glmulti package and function (Calcagno & Mazancourt 2010) in R (R Development Core Team 2016) to identify the best fit model using AIC. If best fit models’ AIC scores were less than two points in difference, we took the average best model across the top five models. This only happened for WHC.

We used linear mixed-effects models to examine relationships between soil properties, groundcover characteristics, and ROI domains. We included selected ROI domains as fixed effects, and included region (Monterey, Santa Cruz, Santa Clara) and plot structure (raised bed versus ground bed) as random effects to account for biophysical, climatic, and structural differences across regions and to focus our analysis on social heterogeneity. The original soil parent material of the garden’s region as determined by the NRCS (i.e., clay loam, clay, silt loam; Table A1 in Appendix) was not a significant predictor of any of the soil properties, so we did not include parent material as a factor in the model. We used the lme function in the lme4 package in R (Bates et al. 2015) to build each model, followed by the InterTest package (Kuznetsova et al. 2015) to run an Analysis of Variance (ANOVA) of type III based on Satterthwaite approximation for denominator degrees of freedom to obtain approximate degrees of freedom and p-values (significance taken at the 5% level) for each ROI domain within each model. The random effects tests were preformed using likelihood ratio tests. In addition, we constructed null models in order to evaluate relative model quality with and without ROI domains using AIC.

To complement the regression analysis, we performed a Principle components analysis (PCA) to further examine variation in soil properties in our sites by groundcover management and their ROI domains that our regression analysis may have overlooked. We created two distance matrices, one for soil variables and one for ROI variables. We used the rda function in the vegan package in R (Oksanen 2015) to do an ordination analysis using Euclidean distance constrained to two axes with all soil variables for each site, and then fit groundcover variables and ROI domains to the ordination. This showed where the gardens are situated relative to their soil properties and socio-demographic characteristics.

### Results

Soil structure and biochemical composition (indicators of soil fertility) and soil water holding capacity (indicators of water conservation services) differed across gardens across the California landscape (Table 2). Mulch groundcover was the strongest predictor of soil properties in the regression analysis (Figure 2; Table A3 in Appendix): SOM, soil C, soil N, and WHC were significantly higher in gardens with more mulch, while BD was significantly lower (Table A3 in Appendix). In addition, soil C:N ratios significantly declined with increasing rock cover. The number of herbaceous plant species did not predict any soil properties.

Socio-demographic characteristics strongly correlated with variation in certain soil properties (Table 3). Soil properties differed with mobility (i.e., people’s ability to overcome isolation). BD was lower, SOM was higher, and C:N ratios were higher in gardens in neighborhoods with higher mobility (Figure 3; Table 3). Soil properties also differed with health/environment opportunity (i.e., an area’s health care access and environmental health). BD was higher, SOM was lower, and C:N ratios were lower in gardens with higher health/environment opportunity (Figure 3; Table 3). Similarly, groundcover characteristics varied with socio-demographic characteristics (Table 3; Table A4 in Appendix). Bare soil cover was greater in neighborhoods with lower housing opportunity (place index; i.e., an area’s availability of affordable housing), and grass cover was greater in neighborhoods with higher mobility and higher housing opportunity. Last, mulch cover was greater in neighborhoods with higher education (i.e., people’s educational assets), higher mobility, and higher housing opportunity (place index) (Figure 3; Table 3), but mulch cover was not predicted by health/environment opportunity. See Table A5 in Appendix for comparisons between models with and without socio-demographic factors, and Table A6 in Appendix for results from all mixed-effects models.

The PCA based on a soil-distance matrix revealed several clusters of gardens corresponding to groundcover management (Figure 4a) and ROI domains (Figure 4b), but that there is variation (Table A7 in Appendix). The first axis (PC1) explained 93.2% of the total variation and the second axis (PC2)

### Table 2. Minimum, maximum and mean values for all soil properties and groundcover management characteristics measured for the 25 gardens.

| Soil properties | Min  | Max  | Mean |
|-----------------|------|------|------|
| Bulk density (g/cm$^3$) | 0.29 | 0.89 | 0.61 |
| Soil organic matter (SOM; %) | 4.38 | 24.74 | 13.95 |
| Carbon to nitrogen ratio (C:N) | 9.99 | 19.29 | 13.57 |
| Soil carbon (Wt%) | 1.61 | 13.68 | 6.18 |
| Soil nitrogen (Wt%) | 0.10 | 0.89 | 0.45 |
| Water holding capacity (WHC) | 35.28 | 84.51 | 57.9 |

| Groundcover | | | |
|--------------|------|------|------|
| Bare soil (%) | 9.73 | 51.23 | 29.29 |
| Grass (%) | 0 | 11.48 | 3.48 |
| Herbaceous (%) | 23 | 59.88 | 39.97 |
| Rocks (%) | 1 | 17.9 | 3.63 |
| Leaf litter (%) | 2.83 | 33.05 | 9.15 |
| Mulch (%) | 0.44 | 52.1 | 22.04 |
| Herbaceous plant species (no.) | 21 | 74 | 45.8 |
explained 5.33% of the variation in the data (the other axes explained <1% and are thus relatively negligible). In corroboration with our regression analysis, the plots reveal that there is a clustering around the use of mulch and mobility, education, and housing (place) domains. Further, the plots reveal that health/environment opportunity is a driver of soil properties, particularly in gardens that are not characterized by the use of mulch. Last, the plots show that for some gardens, groundcover management is more important than the ROI domains, and that one garden is an outlier (lower left quadrant).

Answers from the surveyed gardeners on their soil inputs revealed that almost all gardeners (96%) amend their soils. The majority of soil amendments were compost (68%) and manure (including chicken, horse, and rabbit manure) (20%).

Table 3. Results from linear mixed-effects models of soil properties and selected groundcover management (mulch) predicted by Regional Opportunity Index (ROI) factors (significant factors in bold).

| Model | ROI fixed effects | Sum Sq | Mean Sq | Num DF | Den DF | F value | Pr(>F) |
|-------|-------------------|--------|---------|--------|--------|---------|--------|
| Bulk Density (g/cm³) | Education | 0.03 | 0.03 | 1 | 21.65 | 3.66 | 0.07 |
| | Mobility** | 0.08 | 0.08 | 1 | 23.50 | 8.88 | 0.01 |
| | Housing (place) | 0.02 | 0.02 | 1 | 23.53 | 2.56 | 0.12 |
| | Health/Environment* | 0.05 | 0.05 | 1 | 22.42 | 5.62 | 0.03 |
| | Education | 9.60 | 9.60 | 1 | 23.74 | 0.67 | 0.42 |
| SOM (%) | Housing (people) | 24.22 | 24.22 | 1 | 21.89 | 1.68 | 0.21 |
| Mobility* | 76.33 | 76.33 | 1 | 23.35 | 5.31 | 0.03 |
| | Housing (place) | 59.79 | 59.79 | 1 | 22.25 | 4.16 | 0.05 |
| | Health/Environment* | 76.69 | 76.69 | 1 | 21.50 | 5.33 | 0.03 |
| | Education | 5.54 | 5.54 | 1 | 23.00 | 0.55 | 0.47 |
| C:N Ratio | Mobility* | 12.91 | 12.91 | 1 | 23.00 | 4.60 | 0.04 |
| | Housing (place) | 4.28 | 4.28 | 1 | 23.00 | 1.52 | 0.23 |
| | Health/Environment | 14.57 | 14.57 | 1 | 23.00 | 5.19 | 0.032 |
| | Education** | 506.74 | 506.74 | 1 | 24.00 | 9.04 | 0.006 |
| | Housing (people) | 32.07 | 32.07 | 1 | 24.00 | 0.57 | 0.46 |
| Mulch (%) | Mobility** | 498.43 | 498.43 | 1 | 24.00 | 8.89 | 0.006 |
| | Housing (place)** | 599.82 | 599.82 | 1 | 24.00 | 10.70 | 0.003 |

We show only mulch due to its strong correlation with both soil properties and ROI. Soil C and N were not strongly predicted by opportunity factors (Pearson correlation significant to *p < 0.05, **p < 0.01, ***p < 0.001).

Figure 2. Mulch groundcover management strongly predicted soil properties including: (a) soil organic matter (%) (SOM; \( P = 0.04 \)), (b) water holding capacity (WHC; \( P = 0.04 \)), and (c) soil carbon (Wt%); \( P = 0.05 \)). In turn, neighborhood opportunity domains predicted the amount of mulch cover (d, e, f). Grey areas represent 95% confidence bands.
Urban garden soils are intensively managed by gardeners and are highly variable systems. In this study, groundcover management (mulching) affects soil abiotic and biotic properties indicative of high soil functioning (fertility and high water holding capacity) to provide ecosystem services. Furthermore, socio-demographic characteristics in the form of social opportunities of garden neighborhoods – of both residents and of the area itself – correlate with groundcover management and soil properties. We found that while social advantage is linked to groundcover materials and high functioning soils, gardens in less advantaged neighborhoods (as defined by low values in the health/environment domain) were still able to maintain high functioning soils through other means. We hypothesize that composting, motivation, knowledge and gardener sharing may be some of those methods, in addition to strong garden organization support. The internal garden social-environmental dynamics and the external neighborhood characteristics may be interacting in particular ways to explain the observed variation in soil management across gardens.

Generally, agricultural systems aim to increase soil organic matter, soil nutrients, and C:N ratios (indicative of nutrient cycling regulation), and decrease soil compaction to facilitate crop growth. In our sites, mulching in gardens tends to increase soil functioning, and mulching tends to be more present in neighborhoods with higher education, higher mobility, and higher housing opportunity – all of which are correlated to higher economic opportunity. These relationships suggest that the use of mulch is likely associated with forms of financial capital like disposable income, property and vehicle access. Similar ‘luxury effects’ are shown to drive soil properties in urban residential neighborhoods, where lawns located in wealthier,

**Figure 3.** Soil structure and nutrient properties versus socio-demographic characteristics that were the strongest socio-demographic predictors in the mixed-effects analysis. Neighborhood opportunity domains predicted: bulk density (a, d), soil organic matter (%) (SOM; b, e), and soil C:N ratio (c, f). Grey areas represent 95% confidence bands.

**Figure 4.** Ordinations of garden study sites determined by the 6 soil properties examined in relation to groundcover management (a), and socio-demographic characteristics of garden neighborhoods (ROI domains; b).
high-income neighborhoods have higher soil nutrient content (Hope et al. 2005). Mulch and soil fertility amendments are costly and inaccessible to many urban garden organizations in low-income communities (Reynolds and Cohen 2016). Thus, in our system, mulch seems to be an important driver of soil properties for both soil fertility and water conservation for gardens in more advantaged neighborhoods with higher education, mobility, and residential stability.

However, in gardens in neighborhoods with poor public and environmental health – a domain surprisingly independent of economic opportunity – soils are similarly high functioning (high nutrient content, high water holding capacity) as gardens with high mobility. Yet, not because of mulching, suggesting that in gardens in neighborhoods with indicators of poor public health (e.g., few grocery stores and health centers) and poor environmental quality (e.g., air pollution) other soil management practices or garden social-environmental dynamics are occurring to ameliorate for neighborhood social-environmental disparities. We hypothesize that in these gardens, gardeners are cultivating high functioning soils through other soil management practices that gardeners use, and may be highly self-motivated to improve their health through gardening due to poor public health services and environmental quality in their neighborhood. Social networks, knowledge, sharing, and institutional support (both public and private) may further provide gardeners the ability to manage for high functioning soils in less opportune neighborhoods.

Management practices such as composting, vermicomposting, and cover cropping may be equally effective than mulching at improving soil fertility and water holding capacity in urban agriculture (Beniston and Lal 2012); for example, adding diverse sources of organic matter (green waste, food waste, manure) can increase soil nutrient cycling, improve soil structure, and increase water holding capacity in urban soils and container soils (i.e., raised garden beds) (Atiyeh et al. 2000). These management practices may also be more popular among gardeners (Gregory et al. 2015), and in instances in our system. For example, in gardens where we found less mulch and high soil functioning, surveyed gardeners conveyed that composting and manure additions are preferred to mulch cover due to the nuisance of transportation (many gardeners walk to the garden), agro-ecological beliefs, and frequent tillage (the authors, pers.comm). This is despite being in neighborhoods of relatively high mobility, thus explaining the sinusoidal relationship between mulch and mobility. Moreover, proximity and available transportation to hardware stores are reported barriers for gardeners in gardens both low and high health/environment opportunity neighborhoods that prevent them from transporting mulch to their gardens (the authors, pers.comm). Last, some gardeners seem to utilize their plots more for growing woody shrubs and perennials, which may influence soil properties differently to thereby explain the observed outlier in our analysis. Gardeners are using diverse soil fertility building techniques and agro-ecological practices.

Other social dimensions of gardeners and garden participation may explain indicators of high soil functioning in neighborhoods of poor public and environmental health. Quantitative assessments on the motivations to participate in community gardens include increased consumption of fresh fruits and vegetables, access to greenspace, and health and wellbeing improvements as strong motivators (Armstrong 2000), particularly for gardeners living in neighborhoods associated with social and environmental injustices (e.g., Flint, MI, USA) (Alaimo et al. 2008). Qualitative studies in these cities has also shown that gardening is an act of resistance, a form of empowerment and self-determination to increase fresh food access, foster cultural identity, and promote social-political agency (White 2011). In our gardens, the motivations to ameliorate neighborhood disadvantages, and improve individual and community health through gardening may cultivate high functioning soils. Here, gardeners may be motivated to improve their health and wellbeing and maintain cultural food pathways through access to cultivable soil in a landscape that lacks social-economic equality for minorities. Three gardens in neighborhoods with the lowest health/environment opportunity but highest soil fertility (SOM, soil C) and water holding capacity are some of the most well attended and culturally diverse of the gardens, and gardeners grow a variety of crops reflective of their nation(s) of origin (e.g., Bosnia, Iran, and Vietnam). Crop diversity is associated with diverse soil microbiota like mycorrhizal fungi that drive nutrient cycling and decomposition processes in agroecosystems (Altieri 1999; Van Der Heijden et al. 2008). While we did not find a strong relationship between herbaceous plant diversity and soil fertility here, areas with more crop variety are generally more fertile and contain more nutrients (McDaniel et al. 2014).

Social capital in the form of internal organizational support, gardener social networks and knowledge capital may also counteract neighborhood disadvantages to increase soil functioning. Community gardens generally build social and community capital through increased social interactions and increased social cohesion in areas with few public community spaces (Hancock 2001; Alaimo et al. 2010). As an outdoor classroom and community space, gardens foster educational engagement and ‘learning by doing’ across cultures and
generations (Saldivar-Tanaka and Krasny 2004; White 2011), and facilitate neighborhood community organizing and problem solving among participants (Armstrong 2000). Gardeners share strategies for water conservation and soil contamination remediation (Kim et al. 2014), and share tools and resources (Armstrong 2000). Sharing knowledge builds collective social capital, and sharing tools may even transfer positive microorganisms between gardens to build soil fertility. Furthermore, garden organizations arrange community educational events like composting workshops to boost the knowledge of the gardening community (Wakefield et al. 2007). Gardener bottom-up interactions, or top-down institutional support can thereby provision ecosystem services in less advantaged communities (Schwarz et al. 2016). Indeed, our personal observations in these gardens match with previous findings. In several gardens in more disadvantaged neighborhoods (housing, health/environment, mobility) with high SOM, the gardens receive donations of compost and manure from local farms and animal husbandry organized through garden management or by individual gardeners for all gardeners to use. In two of these gardens, the garden management has provided raised beds, which may help gardeners manage for water and organic matter retention. Together this suggests that social networks and organizational support are likely more important for soil functioning in gardens in more disadvantaged neighborhoods.

In our study, we focused on how social heterogeneity may explain variation in garden soil management given regional biophysical heterogeneity. Variation in certain biophysical or spatial attributes from garden plot to garden plot within gardens may further explain soil properties and the spread around confidence intervals and trends. Variation may be due to the spatial heterogeneity in soil nutrient pools within gardens, as nutrient sources and sinks may be spatially localized in and across garden beds. Nutrient content often exhibits this high variability in urban areas, reflecting both variation in urban biophysical and spatial heterogeneity (climate, land cover, infrastructure) in addition to social heterogeneity (Pickett and Cadenasso 2009). While our quantitative analysis is limited to the spatial and temporal scale of census tract data, and may not be generalizable to every gardener, a majority of gardeners participate in gardens within their neighborhoods (e.g., Kim et al. 2014). Furthermore, while census data is a static and limited measure of neighborhood socio-demographics, the Regional Opportunity Index provides a multi-dimensional and potentially more robust approach to assess social advantage. We did not directly include economic opportunity to instead include other important facets of social life, meaning that income may be a driver of soil functioning and the use of mulch in gardens as it was correlated to both mobility and education domains. However, considering that the neighborhood health/environment domain was not correlated with housing (either place or people indices) or economic opportunity, the importance of social capital in the form of institutional support and social networks holds explanatory weight. Future research that integrates ethnographic approaches and policy assessments in data collection can further identify how social dynamics at multiple units of analysis (gardener, garden, neighborhood, city) shape soils and influence soil-based ecosystem services.

**Conclusion**

Urban agriculture is experiencing a revival at a time of climate variability, unequal resource access, and income inequality. We need to better understand how soil properties and soil fertility change as a function of social contexts in order to improve fresh and safe food access and resource conservation across urban landscapes. This is necessary in both advantaged and disadvantaged neighborhoods, as neighborhoods of low income that are physically and socially isolated may be most vulnerable to changes in resource access due to a lack of either (or both) social and economic capital. We suggest that urban garden management and city planning should realize the important role that leadership and governance plays in off-setting public health and environmental health injustices through both strong social networks within gardens and strong on-the-ground support for residents (Green et al. 2015). For example, simple efforts like providing mulch and compost from institutional bodies may be a relatively easy, cost effective, and a significant step towards equitable access to ecosystem services and resource conservation opportunities.

**Acknowledgments**

We thank the garden organizations that host our research: Aptos Community Garden, City of San Jose Parks and Recreation, City of Santa Cruz Parks and Recreation, Homeless Garden Project, Live Oak Green Grange Community Garden, MEarth, Mesa Verde Gardens, Mid-County Senior Center, Middlebury Institute of International Studies, Obama Way Community Garden, Pacific Grove Community Garden, Salinas Chinatown Community Garden, Santa Clara University, Seaside Giving Garden, UC Santa Cruz. This research was made possible through the field and lab assistance from: J. Burks, H. Cohen, K. Forbush, D. Hafalia-Yackel, Z. Jordan, C. Kirk, M. MacDonald, J. Muramoto, A. Ossola, A. Rubio, J. Tan, and
M. Zavatta. We thank the three anonymous reviewers for constructive comments to improve the manuscript.

Disclosure statement
No potential conflict of interest was reported by the authors.

Funding
This work was supported by a National Science Foundation Graduate Research Fellowship [Grant Number #2016174835] to MHE, and a USDA-NIFA Award [Grant Number #2016-67019-25185] to SMP, BBL, HL, and SJ; and the Environmental Studies Department at the University of California, Santa Cruz.

ORCID
Monika H. Egerer http://orcid.org/0000-0002-3304-0725

References
Alaimo K, Packnett E, Miles RA, Kruger DJ. 2008. Fruit and vegetable intake among urban community gardeners. J Nutr Educ Behav Educ Behav. 40:94–101.
Alaimo K, Reischl T, Allen JO. 2010. Community gardening, neighborhood meetings, and social capital. J Community Psychol. 38:607–621.
Algert SJ, Baameur A, Renvall MJ. 2014. Vegetable output and cost savings of community gardens in San Jose, California. J Acad Nutr Diet. 114:1072–1076.
Altieri MA. 1999. The ecological role of biodiversity in agroecosystems. Agric Ecosyst Environ. 74(1):19–31.
Armstrong D. 2000. A survey of community gardens in upstate New York: implications for health promotion and community development. Health Place. 6:319–327.
Arshad MA, Martin S. 2002. Identifying critical limits for soil quality indicators in agro-ecosystems. Agric Ecosyst Environ. 88:153–160.
Atiyeh RM, Subler S, Edwards CA, Bachman G, Metzger JD, Shuster W. 2000. Effects of vermicomposts and composts on plant growth in horticultural container media and soil. Pedo Biol. 44:579–590.
Barthel S, Isendahl C. 2013. Urban gardens, agriculture, and water management: sources of resilience for long-term food security in cities. Ecol Econ. 86:224–234.
Bates D, Maechler M, Bolker B, Walker, S, Christensen RHB, Singmann H. 2015. lmmer: Linear mixed-effects models using Eigen and S4. R package version. 1.4.
Beniston J, Lal R. 2012. Improving soil quality for urban agriculture in the North Central U.S. Carbon sequestration urban Ecosyst. Delft (The Netherlands): Springer; p. 279–313.
Brown S, Getz C. 2011. Farmworker food insecurity and the production of hunger in California. In Alkon AH, Agyeman J, editors. Cultivating food justice: race, class, and sustainability. Cambridge, MA: MIT Press; p. 121–146.
Calcagno V, de Mazancourt C. 2010. Glmulti: an R package for easy automated model selection with (generalized) linear models. J Stat Softw. 34(12):1–29.
Center for Regional Change. 2015. Regional opportunity index. Davis (CA): University of California at Davis.
Cohen N, Reynolds K. 2014. Resource needs for a socially just and sustainable urban agriculture system: lessons from New York City. Renew Agric Food Syst. 30 (1):103–114.
Community Gardens Program. 2016. Community gardens program 2016 rules and regulations. San Jose (CA). http://www.sanjoseca.gov/index.aspx?NID=599.
Edmondson JL, Davies ZG, Gaston KJ, Leake JR. 2014. Urban cultivation in allotments maintains soil qualities adversely affected by conventional agriculture. J Appl Ecol. 51:880–889.
Effland WR, Pouyat RV. 1997. The genesis, classification, and mapping of soils in urban areas. Urban Ecosyst. 1:217–228.
Green OO, Garrenstani AS, Albro S, Ban NC, Berland A, Burkman CE, Gardiner MM, Gunderson L, Hopton ME, Schoon ML, et al. 2015. Adaptive governance to promote ecosystem services in urban green spaces. Urban Ecosyst. 19(1):77–93.
Gregory MM, Leslie TW, Drinkwater LE. 2015. Agroecological and social characteristics of New York city community gardens: contributions to urban food security, ecosystem services, and environmental education. Urban Ecosyst. 19(2):763–794.
Hancock T. 2001. People, partnerships and human progress: building community capital. Health Promot Int. 16:275–280.
Hope D, Zhu W, Gries C, Oleson J, Kaye J, Grimm NB, Baker LA. 2005. Spatial variation in soil inorganic nitrogen across an arid urban ecosystem. Urban Ecosyst. 8:251–273.
Karlen DL, Mausbach MJ, Doran JW, Cline RG, Harris RF, Shuman GE. 1997. Soil quality: a concept, definition, and framework for evaluation. Soil Sci Soc Am J. 61:4–10.
Kim BF, Poulsen MN, Margulides JD, Dix KL, Palmer AM, Nachman KE. 2014. Urban community gardeners’ knowledge and perceptions of soil contaminant risks. PLoS One. 9:1–9.
Kuznetsova A, Brockhoff PB, Christensen RHB. 2015. lmerTest: tests in linear mixed effects models. R package version 2.0-20. [accessed 2016 Mar 15]; [p. 2016]. https://cran.rproject.org/web/packages/lmerTest
Lin BB, Egerer MH, Liere H, Jha S, Bichier P, Philpott SM. 2018. Local- and landscape-scale land cover affects microclimate and water use in urban gardens. Sci Total Environ. 610–611:570–575.
McClintock N. 2014. Radical, reformist, and garden-variety neoliberal: coming to terms with urban agriculture’s contradictions. Local Environ. 19:147–171.
McDaniel MD, Tiemann LK, Grandy AS. 2014. Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. Ecol Appl. 24:560–570.
McWilliams C. 2004. Soil carbon as the basis for agricultural sustainability: the role of soil type in determining biogeochemical processes. J Soil Water Conserv. 59(1):77–80.
McWilliams C. 2005. The politics of public memory: tourism, history, and ethnicity in Monterey, California. New York (NY): SUNY Press.
McWilliams C. 2007. The politics of public memory: tourism, history, and ethnicity in Monterey, California. New York (NY): SUNY Press.
McWilliams C. 2009. The politics of public memory: tourism, history, and ethnicity in Monterey, California. New York (NY): SUNY Press.
Norkunas MK. 1993. The politics of public memory: tourism, history, and ethnicity in Monterey, California. New York (NY): SUNY Press.
Oksanen J. 2015. Multivariate analysis of ecological communities in R: vegan tutorial. R package version. 1 (7):11–12
Pellow DN, Park LS-H. 2002. The silicon valley of dreams: environmental injustice, immigrant workers, and the high-tech global economy. New York (NY): NYU Press.

Pickett ST, Cadenasso M. 2009. Altered resources, disturbance, and heterogeneity: a framework for comparing urban and non-urban soils. Urban Ecosyst. 12:23–44.

Pouyat RV, Yesilonis ID, Groffman PM, Szlavecz K, Schwarz K. 2010. Chemical, physical and biological characteristics of urban soils. Agron Monogr. 55:119–152.

R Development Core Team. 2016. R: a language and environment for statistical computing. Vienna (Austria): R Foundation for Statistical Computing.

Reynolds K, Cohen N. 2016. Beyond the kale: urban agriculture and social justice activism in New York City. Athens: University of Georgia Press.

Rippey B. 2016. U.S. Drought Monitor: California. National Drought Mitigation Center. https://www.ncs.usda.gov/

Saldivar-Tanaka L, Krasny ME. 2004. Cultivating community development, neighborhood open space, and civic agriculture: the case of Latino community gardens in New York City. Agric Human Values. 21:399–412.

San Jose Parks, Recreation & Neighborhood Services. 2017. Community garden plots. http://www.sanjoseca.gov/index.aspx?NID=599

Santo R, Palmer A, Kim B. 2016. Vacant lots to vibrant plots: a review of the benefits and limitations of urban agriculture. Baltimore (MD): John Hopkins Center for a Livable Future.

Schindelbeck RR, Van Es HM, Abawi GS, Wolfe DW, Whitlow TL, Gugino BK, Idowu OJ, Moebius-Chome BN. 2008. Comprehensive assessment of soil quality for landscape and urban management. Landsc Urban Plan. 88:73–80.

Schmelzkopf K. 2002. Incommensurability, land use, and the right to space: community gardens in New York City. Urban Geogr. 23:323–343.

Schwarz K, Cutts BB, London JK, Cadenasso ML. 2016. Growing gardens in shrinking cities: a solution to the soil lead problem? Sustainability. 8:1–11.

Shuster WD, Bonta J, Thurston H, Warremuende E, Smith DR, Bonta J, Thurston H, Warremuende E, Smith DR. 2005. Impacts of impervious surface on watershed hydrology: a review. Urban Water J. 2:263–275.

Surls R, Borel V, Biscaro A. 2014. Soils in urban agriculture: testing, remediation and best management practices for California community gardens, school gardens, and urban farms. Los Angeles.

US Census Bureau. 2014. American Community Survey. Retrieved from https://www.census.gov/programs-surveys/acs/data.html

van der Heijden MGA, Bardgett RD, Van Straalen NM. 2008. The unseen majority: soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecol Lett. 11:296–310.

Wakefield S, Yeudall F, Taron C, Reynolds J, Skinner A. 2007. Growing urban health: community gardening in South-East Toronto. Health Promot Int. 22:92–101.

White MM. 2011. Sisters of the Soil: urban gardening as resistance in Detroit. Race/Ethnicity Multidiscip Glob Context. 5:13–28.

Wilke BM. 2005. Determination of chemical and physical soil properties. Monitor Assess Soil Biorem. 5:47–95. http://doi.org/10.1007/3-540-28904-6_2

**Appendix. Supplementary tables related to study system and statistical analysis**

**Table A1.** Overview of the urban community gardens sampled in this study: region (County), garden name, management structure, typology, size in acres, age in years, and soil parent material classified by the National Resources Conservation Services.

| Region            | Garden Name                          | Garden management     | Garden Typology | Size (Acres) | Garden Age | Soil parent material (NRCS) |
|-------------------|--------------------------------------|-----------------------|-----------------|--------------|------------|-----------------------------|
| Central           | Alan Chadwick Garden (UCSC)          | Community managed parcel | School          | 2            | 47         | Sandy loam                  |
| Central           | Apts Community Garden                | Allotments            | Church          | 0.5          | 5          | Sandy loam                  |
| Central           | Beach Flats Community Garden         | Allotments            | City            | 0.5          | 20         | Sandy loam                  |
| Northern          | Berryessa San Jose Community Garden  | Allotments            | City            | 2            | 11         | Sandy loam                  |
| Northern          | Charles Street Gardens               | Allotments            | City            | 1.1          | 10         | Clay loam                   |
| Southern          | Community Garden of Salinas          | Allotments            | Church          | 0.25         | 5          | Loam                        |
| Southern          | Coyote Creek San Jose Community Garden| Allotments           | City            | 1            | 21         | Sandy loam                  |
| Northern          | Emma Prusch Park/El Jardin           | Allotments            | City            | 2.5          | 34         | Clay loam                   |
| Southern          | Goodwill Garden                      | Allotments            | Private         | 1.5          | 6          | Sand                        |
| Northern          | Green Thumb                          | Allotments            | City            | 1.3          | 25         | Sandy loam                  |
| Northern          | Guadalupe Garden                     | Allotments            | City            | 1.5          | 8          | Clay loam                   |
| Central           | Homeless Garden Project Farm          | Community managed parcel | Private         | 2.8          | 22         | Sandy loam                  |
| Southern          | Jardin Comunitario Valle Verde       | Allotments            | Private         | 0.25         | 2          | Loam                        |
| Southern          | Jardin de la Comunitad Pájaro        | Allotments            | Private         | 0.1          | 2          | Silt loam                   |
| Northern          | La Colina San Jose Community Garden  | Allotments            | City            | 2            | 37         | Clay                        |
| Northern          | Laguna Seca San Jose Community Garden| Allotments            | City            | 0.75         | 34         | Sandy loam                  |
| Central           | Live Oak Grange Community Gardens    | Allotments            | Private         | 0.5          | 17         | Loam                        |
| Southern          | MEarth Garden & Kitchen              | Community managed parcel | Private         | 1            | 10         | Sandy loam                  |
| Southern          | Mi Jardin Verde                      | Allotments            | Private         | 0.6          | 5          | Loamy sand                  |
| Central           | Mid-County Senior Center             | Allotments            | Private         | 1            | 42         | Sandy loam                  |
| Southern          | MILS Our Green Thumb Community Garden| Allotments            | School          | 0.15         | 6          | Loamy sand                  |
| Southern          | Obama Way Community Garden           | Allotments            | Private         | 0.2          | 5          | Sand                        |
| Southern          | Pacific Grove Community Garden       | Allotments            | Private         | 0.2          | 6          | Loamy sand                  |
| Southern          | Salinas Chinatown Community Garden   | Allotments            | Private         | 0.5          | 8          | Silty clay                  |
| Central           | Trescony Garden                      | Allotments            | City            | 1            | 32         | Loam                        |
Table A2. Results from the Pearson’s Correlation Analysis examining the ROI domains for collinearity.

| ROI1              | ROI2              | Coeff  | P-value |
|-------------------|-------------------|--------|---------|
| CivcOppPeople     | EconOppPeople     | 0.66   | 0.0003  |
| CivcOppPeople     | EduOppPeople      | 0.43   | 0.003   |
| CivcOppPeople     | HealthEnviroOppPeople | 0.60   | 0.0002  |
| CivcOppPeople     | HousOppPeople     | 0.60   | 0.001   |
| CivcOppPeople     | MobilityOppPeople | 0.67   | 0.0003  |
| CivcOppPlace      | CivcOppPeople     | 0.89   | <0.0001 |
| CivcOppPlace      | EduOppPlace       | 0.63   | 0.0001  |
| CivcOppPlace      | EconOppPlace      | 0.14   | 0.51    |
| CivcOppPlace      | EducOppPlace      | 0.32   | 0.11    |
| CivcOppPlace      | EduOppPeople      | 0.25   | 0.22    |
| CivcOppPlace      | HealthEnviroOppPeople | 0.37   | 0.07    |
| CivcOppPlace      | HealthEnviroOppPlace | 0.08   | 0.70    |
| CivcOppPlace      | HousOppPeople     | 0.61   | 0.001   |
| CivcOppPlace      | HousOppPlace      | −0.06  | 0.76    |
| CivcOppPlace      | MobilityOppPeople | 0.60   | 0.0002  |
| EconOppPeople      | EduOppPeople      | 0.51   | 0.01    |
| EconOppPlace       | CivicOppPeople    | 0.36   | 0.08    |
| EconOppPlace       | EducOppPeople     | 0.34   | 0.10    |
| EconOppPlace       | EduOppPlace       | 0.61   | 0.001   |
| EconOppPlace       | EduOppPeople      | 0.46   | 0.02    |
| EconOppPlace       | HealthEnviroOppPeople | 0.42   | 0.04    |
| EconOppPlace       | HousOppPeople     | 0.21   | 0.31    |
| EconOppPlace       | MobilityOppPeople | 0.40   | 0.05    |
| EducOppPlace       | CivicOppPeople    | 0.55   | 0.004   |
| EducOppPlace       | EduOppPeople      | 0.43   | 0.03    |
| EducOppPlace       | EduOppPeople      | 0.78   | <0.0001 |
| EducOppPlace       | HealthEnviroOppPeople | 0.68   | 0.0002  |
| EducOppPlace       | HousOppPeople     | 0.03   | 0.87    |
| EducOppPlace       | MobilityOppPeople | 0.54   | 0.01    |
| HealthEnviroOppPeople | EconOppPeople | 0.45   | 0.02    |
| HealthEnviroOppPeople | EduOppPeople | 0.64   | 0.001   |
| HealthEnviroOppPeople | HousOppPeople | 0.39   | 0.05    |
| HealthEnviroOppPeople | MobilityOppPeople | 0.26   | 0.21    |
| HealthEnviroOppPlace | CivicOppPeople | 0.26   | 0.21    |
| HealthEnviroOppPlace | EduOppPeople | 0.02   | 0.91    |
| HealthEnviroOppPlace | EducOppPlace | 0.23   | 0.26    |
| HealthEnviroOppPlace | EduOppPeople     | 0.13   | 0.54    |
| HealthEnviroOppPlace | EduOppPeople     | −0.03  | 0.89    |
| HealthEnviroOppPlace | HealthEnviroOppPeople | 0.18  | 0.40    |
| HealthEnviroOppPlace | HousOppPeople     | 0.05   | 0.80    |
| HealthEnviroOppPlace | HousOppPlace      | −0.24  | 0.26    |
| HealthEnviroOppPlace | MobilityOppPeople | 0.25   | 0.24    |
| HousOppPeople      | EconOppPeople     | 0.58   | 0.003   |
| HousOppPeople      | EduOppPeople      | 0.18   | 0.39    |
| HousOppPlace       | CivicOppPeople    | −0.25  | 0.25    |
| HousOppPlace       | EconOppPeople     | 0.09   | 0.67    |
| HousOppPlace       | EconOppPlace      | −0.32  | 0.12    |
| HousOppPlace       | EducOppPlace      | −0.37  | 0.08    |
| HousOppPlace       | EduOppPeople      | −0.20  | 0.34    |
| HousOppPlace       | HealthEnviroOppPeople | −0.25 | 0.23    |
| HousOppPlace       | HousOppPeople     | 0.39   | 0.06    |
| HousOppPlace       | MobilityOppPeople | −0.40  | 0.05    |
| MobilityOppPeople  | EconOppPeople     | 0.45   | 0.02    |
| MobilityOppPeople  | EduOppPeople      | 0.29   | 0.16    |
| MobilityOppPeople  | HousOppPeople     | 0.04   | 0.86    |

Table A3. Pairwise correlation matrix among groundcover management variables.

| Bare soil % | Grass % | Herbaceous % | Rocks % (arc sin) | Leaf litter % (arc sin) | Mulch % |
|-------------|---------|--------------|-------------------|-------------------------|---------|
| Bare soil % | 0.38    | 0.59         | 0.79              | 0.16                    | 0.001   |
| Grass %     | 0.38    | 0.17         | 0.95              | 0.97                    | 0.86    |
| Herbaceous %| 0.59    | 0.17         | NA                | 0.07                    | 0.41    |
| Rocks % (arc sin) | 0.79 | 0.95 | 0.07 | NA | 0.65 |
| Leaf litter % (arc sin) | 0.16 | 0.97 | 0.41 | 0.65 | NA |
| Mulch %     | 0.001   | 0.86         | 0.05              | 0.55                    | 0.11    |

Table A4. Results from best fit generalized linear models model selection. Most soil properties were best explained by mulch cover.

| Model             | Explanatory Variable | Estimate | SE  | t value | Pr(>|t|) | AIC    |
|-------------------|----------------------|----------|-----|---------|----------|--------|
| Bulk Density      | Mulch %              | −0.01    | 0.00| −3.69   | 0.001    | −33.65 |
| SOM %             | Mulch %              | 0.20     | 0.09| 2.23    | 0.04     | 162.04 |
| C:N               | Rocks %              | −1.46    | 0.59| −2.50   | 0.02     | 99.14  |
| Wt% N             | Mulch %              | 0.11     | 0.05| 2.08    | 0.05     | 129.13 |
| Wt% C             | Mulch %              | 0.01     | 0.00| 2.09    | 0.05     | 3.72   |
| WHC               | Mulch %              | 0.50     | 0.22| 2.24    | 0.04     | 198.11 |

Table A5. Model fit for models predicting soil properties and groundcover management by socio-demographic variables (i.e., ROI domains) as fixed effects versus those without (i.e., null models with only random effects).

| Model | AIC | BIC | logLik | deviance | df.resid |
|-------|-----|-----|--------|----------|----------|
| BD-ROI | 26.7 | 16.1 | 22.4 | −44.7 | 15 |
| BD-Null | −21.7 | −16.9 | 14.9 | −29.7 | 21 |
| SOM-ROI | 65.9 | 68.6 | 137.3 | 15 |
| SOM-Null | 168.6 | −77.9 | 155.7 | 21 |
| CN-ROI | 117.2 | −44.5 | 89 | 14 |
| CN-Null | 117.7 | −49.5 | 99 | 20 |
| C-ROI | 117.6 | −49.7 | 99.4 | 14 |
| C-Null | 134.5 | −60.9 | 121.8 | 20 |
| N-ROI | 4.9 | 11.2 | −22.4 | 14 |
| N-Null | 10.5 | 1.1 | −2.2 | 20 |
| WHC-ROI | 206.2 | −89 | 178 | 14 |
| WHC-Null | 207.5 | −97.4 | 194.8 | 20 |
| Mulch-ROI | 193.3 | −82.4 | 164.7 | 15 |
| Mulch-Null | 209.8 | −98.5 | 197 | 21 |
| Bare-ROI | 202.7 | −87 | 174.1 | 15 |
| Bare-Null | 207.2 | −95.9 | 191.9 | 21 |
| Grass-ROI | 140.8 | −56.1 | 112.2 | 15 |
| Grass-Null | 143.6 | −65.4 | 130.7 | 20 |
| Rocks-ROI | 66 | −18.7 | 37.4 | 15 |
| Rocks-Null | 55.2 | −21.2 | 42.4 | 21 |
| Litter-ROI | 74.4 | −22.9 | 45.8 | 15 |
| Litter-Null | 63.8 | 4.8 | 50.2 | 21 |

BD: bulk density; SOM: soil organic matter; C:N: carbon to nitrogen ratio; C: % weight of soil carbon; N: % weight of soil nitrogen; WHC: water holding capacity.
### Table A7. Principle components analysis loadings for ground-cover characteristics (top) and socio-demographic characteristics (i.e., ROI domains) measured in the gardens.

| PC1  | PC2  |
|------|------|
| Bare soil % | −0.44 | 0.90 |
| Grass %    | −0.83 | −0.56 |
| Herbaceous % | 0.56 | 0.83 |
| Rocks % (arc sin) | −0.90 | −0.44 |
| Leaf litter % (arc sin) | −0.58 | −0.81 |
| Mulch %    | 0.99  | −0.11 |
| Education: People | −0.64 | −0.77 |
| Housing: People | −0.11 | 0.99 |
| Mobility: People | 0.95 | 0.31 |
| Housing: Place | 0.61  | −0.79 |
| Health/Environ: Place | −0.84* | 0.55 |

Pearson correlation significant to *p < 0.05, **p < 0.01, ***p < 0.001.