To the University of Wyoming:

The members of the Committee approve the thesis of Shannon Conk presented on 8/4/2015.

Christine M. Porter, PhD, Chairperson

Emily Guseman, PhD, Member

Randa Jabbour, PhD, External Department Member

APPROVED:

Dr. Derek Smith, Director, Kinesiology & Health.

Joseph F. Steiner, Pharm.D., Dean, College of Health Sciences

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Health and other benefits associated with gardening are well studied. Less is known about the actual quantity of food that gardens produce. A better understanding of garden yields and factors that influence yields is needed. OBJECTIVES: The Team GROW study examined the agricultural and economic productivity and nutritional significance of home and community gardens in Laramie, WY. Additionally, yield-influencing factors of soil and temperature were compared to yield outcomes to better understand potential causes of garden yield variation. METHODS: Data from the ongoing Team GROW study in Laramie was used to calculate yield, economic value, and nutritional significance of study gardens. A total of 31 gardens were assessed between 2012-2014 with 56 total cases— multiple gardens having participated in 2 or 3 years of data collection. Garden area was measured and study participants weighed and recorded each garden harvest. With this information, harvest amounts were calculated as a yield rate (lb/ft^2). Economic value was assigned to each garden based on farmer's market prices and crops grown in gardens. Nutritional significance of gardens was calculated by weighing harvested crops in the amount of a single serving and then applying that calculation to the total amount of each crop produced per garden. Soil samples were taken in each garden and each year and tested at the CSU soil-testing lab. Temperatures during the harvest season of each year of Team GROW were collected using the Weather Underground historical database. RESULTS: The average garden yield for our study was 0.51 lb/ft^2, comparable to other home and community garden harvest studies and approaching yields typical of conventional farming (0.6 lb/ft^2) even despite climatic challenges associated with the area. Nutritionally, study gardens provided an average of 77% of the vegetable servings required for a single adult over the course of an entire year. The average economic value of garden produce was $436 per harvest season with an average value rate of $1.80 per ft^2. Comparisons of soil health and weather against yields were inconclusive. CONCLUSIONS: Team GROW results show that gardens provide nutritionally and economically meaningful amounts of food for a household. Of the factors assumed to influence garden productivity, none seemed to have more than a weak effect on yields. Team GROW results suggest that home and community gardens can play an important role in vegetable provision for households and communities.

QUANTIFYING YIELDS OF HOME AND COMMUNITY

GARDENS IN LARAMIE, WY

by
Shannon Conk

A thesis submitted to the Division of Kinesiology and Health

and the University of Wyoming

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CHAPTER ONE – INTRODUCTION

The purpose of this research project was to document the yield rates and rate variation of household food gardens in Laramie, Wyoming. This research was and continues to be conducted in order to quantify and better understand causes of variation in the productivity of home and community food gardens. Previous research quantifying garden productivity rates and causes of rate variation is limited. No previous studies have assessed nutritional significance of gardens nor have any studies been conducted in a zone 4 climate.

This research is focused on food grown in home and community gardens, which is abbreviated throughout this paper as HCGs. Within this paper, the HCGs and the individuals and families that tend them make up the Team GROW study. Team GROW (Garden Researchers of Wyoming) is a harvest measure project in Laramie, Wyoming funded by the USDA Food Dignity research project grant. At times throughout this paper, I use 'we' and 'our' in which case I am referring the number of researchers and participants involved in the study.

Background

Over the past decade, the US has experienced a resurgence of home and community gardens unseen since World War II (WWII).[1] Increasing popularity of HCGs correlates with the socioeconomic climate of the country. During recessions or economic slow-downs, household-level food production increases in popularity as a way to buffer increasing food prices and/or decreasing incomes and improve self-sufficiency.[1] During the 2009 recession there was a 19% increase in household gardens. Like Victory Gardens in WWII, these gardens were given their own name, Recession Gardens.[1] Interest in gardening and local foods has continued to increase, even as the national economy has gained traction.[2,3] The most recent measurements estimate approximately 18,000 community gardens in the US and Canada in

2011, and 43 million gardening households in the US in 2009.[3,4] Given this trend, understanding the productivity of HCGs and has important implications for household food provision.

HCGs and their benefits

Typically, HCGs are small in scale and are implemented for a wide range of reasons including food production, leisure, and cultural preservation and expression.[1] Their size is often limited to yard space or pre-determined community garden plot sizes. Gardens allow for a household to not be just a consumer but also a producer. Having custody of the garden plot and limited geographical separation between the site of production and consumption also allows growers to control the inputs used in their gardens.

HCGs provide a wide range of documented benefits to the gardener and surrounding community. First and foremost, HCGs improve access to fresh produce.[1,5,6] Moreover, numerous studies have found that HCGs not only increase access, but consequently increase fruit and vegetable consumption in gardening participants. A study based in California measured a 10% increase in fruit and vegetable consumption of school and community gardening participants.[5] Another in Flint, MI found that 32% of households participating in a community garden ate 5 servings of fruits/vegetables per day compared to only 18% of households not participating in a community garden.[7] A 2012 study by Carney et al. that looked at pre- and post- garden behaviors found that vegetable intake of ‘‘several times a day’’ increased 67% from the pre-garden baseline for adults and increased 40% for children. Participants were also less concerned about inability to afford and provide a sufficient amount of food for their household during the gardening season.[6] A study on community gardeners in Denver, CO found that after adjusting for socioeconomic status (SES), health, and social/psychological covariates, community gardeners consumed nearly one serving more of fruits and vegetables than home gardeners and nongardeners per day.[8] A number of other studies have also found increased fruit and vegetable consumption among individuals with a HCG.[9,10]

Along with diet, HCGs improve levels of physical activity and reduce sedentary time. The same California study that found a 10% increase in fruit and vegetable consumption in school and community garden recipients reported a 6% increase in physical activity sessions in individuals who began gardening. Other studies have also reported increases in physical activity associated with gardening.[11,12] A study that looked specifically at BMI found that this measure was significantly lower in community gardeners compared to their neighbors and siblings.[13] These results are cross-sectional, and therefore might not be causal, but they do suggest that BMI could be inversely associated with gardening participation, especially given studies that have shown a positive correlation between gardening and physical activity or improved diet.

Studies also suggest that HCGs can improve emotional and social wellbeing. Gardens provide opportunities for decreasing stress, and community gardens specifically have been shown to increase social interactions and wellbeing.[1,11,14] As an educational tool, many K-12 schools have started school gardens as a way to provide a hands-on learning experience for students. School gardens are especially important for students who may not be exposed to fruits and vegetables otherwise and also because of the importance of establishing healthy habits at a young and impressionable age.[9] Some community gardens also provide opportunities to help socially excluded populations including “at-risk” youth, homeless people, and refugees.[15] Also, refugees and immigrant populations may benefit from opportunities to grow culturally important crops that may not be available at local food outlets.

Community gardens may also positively affect property values in their nearby vicinity. A study in New York City found that sale prices of residential properties within 1,000 feet of a community garden were significantly higher than residential properties that were outside 1,00 feet of a community garden.[16] Other residential benefits include increased neighborhood attachment, improved aesthetics, and decreased crime.[1,8] Gardens also improve the ecological environment by enabling ecosystem services such as pollination, water and air filtration, habitat, open-space preservation, and decreasing the carbon footprint of the produce consumed by gardeners.[1]

Current Health Challenges

My peers and I are a part of the first generation that is expected to live shorter lives than our parents.[17] One-third of the nation's adults and one-sixth of our children are obese.[18] Cardiovascular disease kills more individuals in the U.S. than any other cause.[19] While these and other diseases arise from a number of risk factors, a diet high in saturated fat and processed foods with insufficient fruit and vegetable consumption is often partly to blame. Only one in ten children and one in five adults eat the recommended amount of vegetables.[20]

A number of factors determine an individual's health status with SES being one of the most powerful.[5] Financial and geographical food accessibility may be one mechanism in this complex causal web of poor health outcomes. The USDA defines a food desert as an "area in the United States with limited access to affordable and nutritious food, particularly such an area composed of predominantly lower income neighborhoods and communities."[21] Nationally, approximately 22% of households without a vehicle and 38% of low-income households are more than one mile from the nearest grocery store.[21]

Beyond physical food access, financial access affects an even greater proportion of the population. During 2012, 14.5% of households and 20% of households with children in the US qualified as 'food insecure.'[21] The definition of food insecurity by the USDA is: "At times during the year, these households were uncertain of having, or unable to acquire, enough food to meet the needs of all their members because they had insufficient money or other resources for food".[22] Studies have suggested that community and home gardens have the potential to address both food insecurity and food deserts by moving food production and supply closer to demand.[1] A handful of studies in the past decade have also tackled the question of garden productivity, since little had been known about this. The findings of these studies are discussed below.

Previous HCG Yield Research

Six studies have quantified harvest yields of home, community, and/or school food gardens with varying results (**Error! Reference source not found.**). Four of these studies were published in peer-reviewed journals. These studies used similar methods to quantify harvest yields. These methods all included the measurement of garden area and weighing of all produce grown to calculate a yield total and a productivity rate. The six studies provide eight years of data (two studies collected two years of data). Yields from these studies ranged from .33 lb/ft^2 in New York City to 1.4 lb/ft^2 in Philadelphia, PA with an average yield of .61 lb/ft^2.[23-25] The typical yield for HCGs according to a 2009 report by the National Gardening Association is .5 lb/ft^2.[3] Only two studies, Algert et al. and Pourias et al., reported a range of productivity for their study garden plots; the others reported summary statistics only.

Several studies have monetized harvests from HCGs and have used this to estimate the significance of harvests in terms of food security. Different studies used different methods to monetize harvests, as discussed in the monetizing variation section below and summarized in Table 1. The range of economic value of harvests in these previous studies ranged from $1.07 to $3.34 per square foot of growing area. More details on methodology and results for each study are contained in Appendix A. Table 1 – Summary of Previous Harvest Study Characteristics and Results**Error! Reference source not found.**Note: *Italicized* studies did not appear in a peer-reviewed journal. See Appendix A for more details.

Yield Measurement Method Variation

Many of these studies used pounds per square foot (lb/ft^2) as the metric to illustrate productivity; studies that used other units were converted to (lb/ft^2) for the purpose of comparison. There was some variation in how the area of garden plots was measured. Some studies included non-growing areas such as walkways and trees in their area measurements. This understates yield rates vs. the studies that excluded such non-growing areas of gardens, though is more comparable to farm acreage calculations used to estimate agricultural productivity. One study measured 'developed area' which accounts for successive plantings in a single season by multiplying area by the number of plantings completed in that area.[26] All but two studies (Algert et al., Pourias et al.) extrapolated garden yield data to a larger area to estimate food production or food production potential (see 'Extrapolation' column in Appendix A). The area to which yields were extrapolated varied by study from smaller extrapolations (a portion of plots in a community garden extrapolated to the entire community garden)[23] to much larger extrapolations (10 gardens extrapolated to an entire urban area of a city)[27]. Another variation between published studies is what "garden" refers to. In most cases, a single garden unit is a single plot, however in both studies published by Vitiello, a single garden encompasses an entire community garden, which contains within it multiple plots.[23,24] The study published by Pourias et al. included shared and family gardens in Paris, France, some of which operate under a more communal management plan.[26]

Monetizing Harvest Value Methods

Economic values of garden harvests have a wide range due to variations in garden yields, crops grown, and in the market benchmarks used to monetize them. Vitiello (2009) and Gittleman (2012) explicitly state that most of the measured gardens used organic gardening methods. All studies except for Algert et al (2012) used monetary values that embodied the premium prices that local and organic produce command (see **Error! Reference source not found.**). Farmer's market prices were often used to capture this value. Cooperative market prices and conventional grocers prices were used as well. Part of the value variation therefore is due to whether researchers used more expensive farmer's market prices, or less expensive prices from a conventional grocery store. Because HCG food production often employs organic, ecological gardening methods, farmer's market or co-op prices are arguably the most comparable HCG produce.[25,28]

Rationale for this Research

Few studies have conducted research on the quantitative outcomes of gardens. Understanding the productivity of HCGs is necessary given the important policy implications of garden productivity in areas of agriculture, public health, community development, and land-use. Only a handful of research projects have quantified harvests from home and community gardens, and all have been very recent – since 2008.

Of these research projects, only two have data for two years. At least some of their participants may have collected data both years but their published results do not provide intra-gardener comparisons. Harvest measures across multiple years allow for more representative data and may provide insight into causes of productivity variation. Garden productivity is highly variable, including due to factors such as rainfall, temperatures, weather events, etc. that change from year to year. Previous research has not examined how these factors might affect garden yields from year to year. Also, previous studies have been in areas rated at a 5a plant hardiness zone or higher, leaving a research gap in more challenging climates.

Research Purpose and Questions

The purpose of this research project was to calculate and assess yields and yield variation – both between gardeners and between gardening seasons – of home and community gardens in Laramie, Wyoming. We also converted these yields to economic value and nutritional significance measures and examined potential causes of yield variation.

The primary research questions were:

1. How productive are HCGs in Laramie, and what is their range of their yields?
    - 1a. What is the economic value of food produced in HCGs?
    - 1b. To what extent can HCG food production contribute to meeting the USDA recommendations for vegetable servings?
2. How might factors such as soil, weather, and climate influence the productivity variations within and between HCGs?
3. What methods have been used to quantify HCG productivity and how do these compare to our methods?

Our data consist of 3 years of harvest measurements by 28 gardeners, with three participants collecting data all three years, and many participants collecting data for two of the three years (n=12) and some gardeners collecting data during a single year for a total of 56 cases. Multiple years of data enables us to compare productivity both across and within seasons. As mentioned, previous garden productivity studies have taken place in areas with longer growing seasons (CA, NY, PA, WI, Paris, Montreal), therefore our data gives some insight into the implications of growing conditions and climate for HCG productivity. Data from our study are the first from USDA plant hardiness zone 4 or lower – Laramie sits in zone 4b, a colder climate than any previously published harvest measure research.[29]

CHAPTER TWO - DESIGN AND METHODOLOGY

This paper includes a substantial portion of the results from the first three years of the Team GROW (Gardener Researchers of Wyoming) research project, a joint effort between the non-profit Feeding Laramie Valley (FLV) and the University of Wyoming (UW). Team GROW is funded under a USDA grant for a larger community food system project called Food Dignity.

Citizen Science

Team GROW piloted in 2012 to design and trial research to quantify the productivity of household gardens in Laramie, WY. Harvest measure protocols from Team GROW were designed and conducted by citizen scientists in collaboration with FLV and UW team members. Community members are often excluded in academic research leading to a gap in the literature or inaccurate research, or when included, communities and community members are often left feeling exploited and disempowered.[25] In the case of Team GROW, the gardeners in the 2012 pilot year of the study designed what data would be collected and how, and then implemented the protocol they designed with support from FLV and the UW research team.

Study Site and Participant Selection

FLV recruited the participants for this study from the local Laramie Valley community, which includes the small city of Laramie, Wyoming and the surrounding rural area. Laramie itself is home to about 32,000 people with only another 5,600 in the rest of the surrounding county.[30] It is also the location of Wyoming's only four-year university. Sitting at 7,220 feet in elevation and in USDA plant hardiness zone 4b, the climate of the area poses a challenge for food production with a 51 day growing season and extreme temperature shifts.[29,31] Despite these challenges, there are numerous successful growing operations within the county including Community Supported Agriculture (CSA) farms, a UW student farm, 3 community gardens and, likely, hundreds of home gardens.

Team GROW collected harvest data during 2012, 2013, and 2014. For the pilot study in 2012, five experienced gardeners were invited by FLV to co-design and pilot the study with their own gardens. They were recruited from local gardening networks including FLV, Laramie Garden Club, Laramie Local Foods and Laramie community gardens. Experienced gardeners with leadership experience were invited and all who were invited agreed to participate in the pilot study, including in shaping its design.

The following year (2013), a more diverse group of gardeners was invited to participate in the project. Participant recruitment included the use of flyers throughout Laramie, emails, and phone calls as well as an FLV-sponsored gardening workshop that aimed to reach people of color and low-income households. These efforts resulted in a more diverse group of participants in terms of age, gender, socio-economic status, and gardening experience – something that was important to those involved with the study. In 2014, participants from the previous year were invited to participate another year.

This study was approved by the UW's Institutional Review Board, and all study participants consented to participation. In recognition of taking the time to record their harvest and of their input into the research project, participants were given $100 at the beginning of the growing season along with a small scale for weighing produce. Participants also received the results from professional soil tests. Many of the participants were very interested in their productivity of the potential productivity of gardens in general and enjoyed seeing the results at the end of the season.

Methodology: Data Collection

Data was collected during the 2012, 2013, and 2014 growing seasons. Pilot data was collected in 2012 with 5 participants who tended 9 plots. In 2013, the project was expanded to include 25 participants with 33 plots. In 2014, only participants from 2013 were invited to re-enlist. Thirteen participants with 15 plots all agreed to collect data for another year. In 2012 and 2013, Porter's graduate student Peggy McCrackin measured the square footage of each garden plot, took soil samples, and tabulated results reported by gardeners. In 2014, I collaborated with Livy Lewis, also a UW graduate student with Porter, to measure each plot, collect soil samples for lab testing, and photograph each garden. Plots were measured excluding areas that were not food-production areas such as stepping-stones, walkways and non-fruiting trees. Participating gardeners classified and weighed all produce harvested. Harvest measures were recorded on a provided paper or electronic spreadsheet form that detailed the date, crop type, weight (oz), food use (eaten, stored, shared), and a space for notes (See Appendix B). Monthly email were sent to Team GROW participants as a reminder to send their data via email in an excel file or physical mail to the FLV building. Data from each plot was collected, then compiled into Excel files and analyzed both separately by plot as well as by year.

Soil samples for each garden all three years were collected by UW graduate students and were taken for testing at the Colorado State University Soil, Water and Plant testing laboratory (the cost per sample was $31, covered by project funds). Soil samples were taken in accordance with lab directions and protocol including the number of locations within each garden soil was taken from (≥5), depth of extracted soil (6 inch column), amount of soil extracted (2 cups), and proper storage prior to submitting to lab (refrigerated in clean plastic container).[32]

Temperature data for the duration of the harvest season was also collected. The metric we used for temperature was Growing Degree Days (GDD), a heat unit (HU) measurement specific to crop production. GDD takes into account the performance curve of crop growth using temperature minimums, optimums, and maximums.[33] GDD data was accessed via the historical weather tool on the Weather Underground website.[34] Dates for average first and last harvest of each year were entered to calculate total GDD units for each study year.

Methodology: Data Analysis

The primary data of interest for the purpose of this paper are harvest yield, economic value, and nutritional significance. Multiple analyses were conducted on the three years of collected data including garden yields, monetary value of harvested crops, number of vegetable servings produced, crop diversity and food use (eaten, stored, shared).

Garden yields were measured in accordance with common agricultural practice – a rate of weight over area. Crop weight is summarized and then divided by total growing area to calculate a rate expressed in lb/ft^2; at large-scale farms and agricultural operations the unit used is kilograms per acre or bushels per hectare and yield is referred to as crop yield or agricultural output. Economic value of garden yields was calculated using local farmer's market prices; if unavailable, local grocery store prices of organic produce were used. Value depends on weight and crop type and was calculated in three ways: per garden plot, per square foot, and per pound. These calculations allowed us to determine the economic value of each garden plot's harvest for the household as well as to compare to other garden yield studies that calculated value per square foot or value per pound of harvested produce.

Additionally, we calculated the nutritional significance of harvest yields by converting annual garden yields into vegetable servings. This was measured by weighing each crop produced in study gardens (three trials) in the amount designated as a serving by the USDA to determine how many servings of vegetables each HCG produced. Each crop was prepared in the way it is typically consumed before the three weight trials. The USDA vegetable serving recommendation for an adult is 2.5 cups of vegetables per day, except for raw leafy vegetables, which require 5 cups per day. With the weight per serving metric we calculated the number of vegetable servings produced and then applied the extent to which our study gardens met nutritional recommendations for annual vegetable consumption. For example, if a garden produced 10 lbs of spinach, we would perform the following calculation to determine its nutritional significance:

10 lbs = 160 oz
160 oz ÷ 0.48 oz spinach/cup = 333.33 cups
333.33 cups ÷ 5 cups raw leafy greens / daily vegetable serving = 67 daily vegetable servings

In other words, we used our 3-trial measurement of .48 ounces/cup and the established 5 cups of raw leafy greens per daily vegetable serving to calculate that the 10 lbs of spinach produced equates to 67 days of vegetable servings fulfilled.

Aside from group performance, our multi-year data set allows for comparisons across years and gardens to examine potential causes of yield variation. There are data for three consecutive years for three garden plots, and data for two consecutive years for 12 plots. Averages and ranges of all three measures of productivity (weight, vegetable servings, economic) were compared between years between each set of data (2012, 2013, and 2014) as well as between individual plots for those that were a part of the study for at least two years. There was the expected variation in these comparisons, and temperatures, harvest season length and soil test results for each year were assessed to determine whether there is any relationship between these factors and productivity.

Results from soil tests were distributed to gardeners and included measurements of 16 soil health indicators and guidance on amending soil and addressing problem areas.[1] Soil data from soil tests provided for each garden were used to compare nitrogen, phosphorous, potassium, and organic matter levels against yield. Temperature data represented through growing degree days (GDD) was also collected and compared to yield. In both cases data were plotted and a linear regression was performed to assess the relationship between the two variables.

CHAPTER THREE – RESULTS

Table 2 below shows summary data from the 3 years of our study. Yields were 0.44 lb/ft^2 in 2012 and 0.52 lb/ft^2 in 2013 and 2014 with a 3-year average of .51 lb/ft^2. Yield varied greatly between garden plot with the lowest reported yield of 0.01 lb/ft^2 in 2013 and the highest reported yield of 2.06 lb/ft^2 in 2012. Monetary value increased each year in both economic indicators – value per square foot and value per pound. Gardens showed large variations between economic values per plot, with a low of $28.03 in one 2014 plot (148 ft^2) and a high of $2,598.67 in another (391 ft^2) during 2013. As an economic rate per garden area, values ranged from $0.03/ft^2 to $6.69/ft^2. Economic value for the average plot over the three years of the study was $437 with an average rate of $1.38/ft^2.

Nutritional significance varied greatly depending on yield, harvested crops, and plot size of the garden. In order to have a figure for comparison, nutritional significance (as indicated by number of days

[1] Soil test results included pH, electrical conductivity, lime, texture estimate, Sodium absorption ratio, organic material, nitrate, phosphorous, potassium, zinc, iron, manganese, copper, boron, and gypsum.

the total garden harvest would supply one adult with the recommended daily 2.5 cups of vegetables) was standardized to 253 ft^2 (average 3-year study garden size). A garden of this average size produced 72%, 75%, and 78% of the annual vegetable servings recommended for an adult in 2012, 2013, and 2014, respectively. Some individual plots produced more than 100% of the annual vegetable servings recommended for a single adult.

Table 2 – Results from Team GROW, 2012-2014

Team GROW		**2012**	**2013**	**2014**
Participants (n)		5	31	12
Gardens (n)		9	33	14
Average garden size (ft^2) (Range, median)		317 (120-890, 150)	283 (58-1,006, 150)	191 (45-534, 150)
Average harvest season (days) (Range, median)		100 (44-170, 94)	103 (167-212, 104)	118 (54-239, 106)
Average number of crop types per garden (Range, median)		18 (11-28, 18)	17 (4-51, 15)	15 (9-41, 12)
Average total season harvest (lbs) per garden. (Range, median)		141 (43-342, 94)	137 (4-656, 73)	99 (10-486, 68)
Use of harvested food	Eat	51%	36%	39%
	Store	19%	30%	45%
	Share	30%	34%	17%
Average value of harvest per garden (Range, median)		$459 ($151 – $914, $399)	$447 ($28 – $2,599, $241)	$401 ($28 - $2,102, $192)
Average value per pound (Range, median)		$3.27 ($2.36 - $4.67, $3.07)	$3.54 ($2.12 - $7.74, $3.72)	$4.06 ($2.48 – $5.94, $3.94)
Average value per ft^2		$1.45	$1.85	$2.10

(Range, median)	($0.69 - $6.69, $1.09)	($0.03 - $6.64, $1.55)	($0.19 - $5.03, $1.41)
Yield: lbs/ft^2 (Range, median)	0.443 (0.16 - 2.06, 0.38)	0.523 (0.01 - 1.68, 0.42)	0.517 (0.12 - 1.16, 0.35)
Vegetable Servings/Year	94%	75%	59%
Vegetable Servings/Year/264 ft^2	72%	75%	78%

Note: Number of gardens exceeded number of participants each year as some participants had two separate gardens involved in the study. Harvest season was calculated using the first and last harvest as documented by participants.

Soil Results

Organic matter, nitrate, phosphorous, and potassium levels from each study garden were compared to garden yields. A linear regression was performed for each of the mentioned soil indicators relative to yield. Figures 1-4 illustrate these relationships.

Figure 1 – Soil Organic Matter Compared to Yields in study gardens

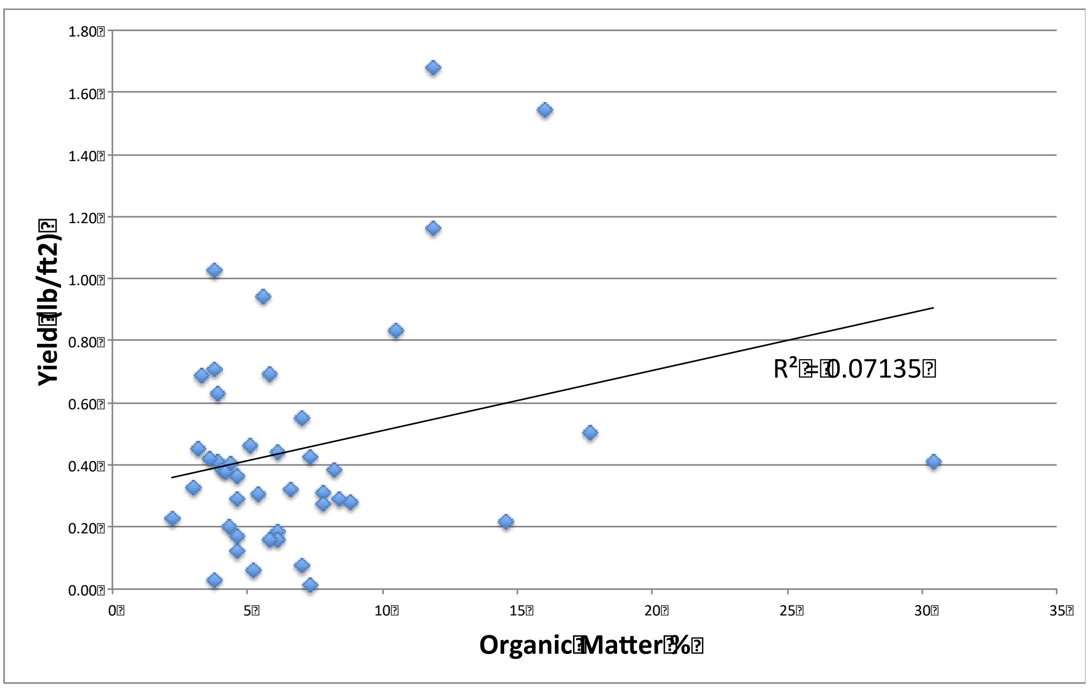


Figure 2 – Soil Nitrate Levels Compared to Yield in Study Gardens

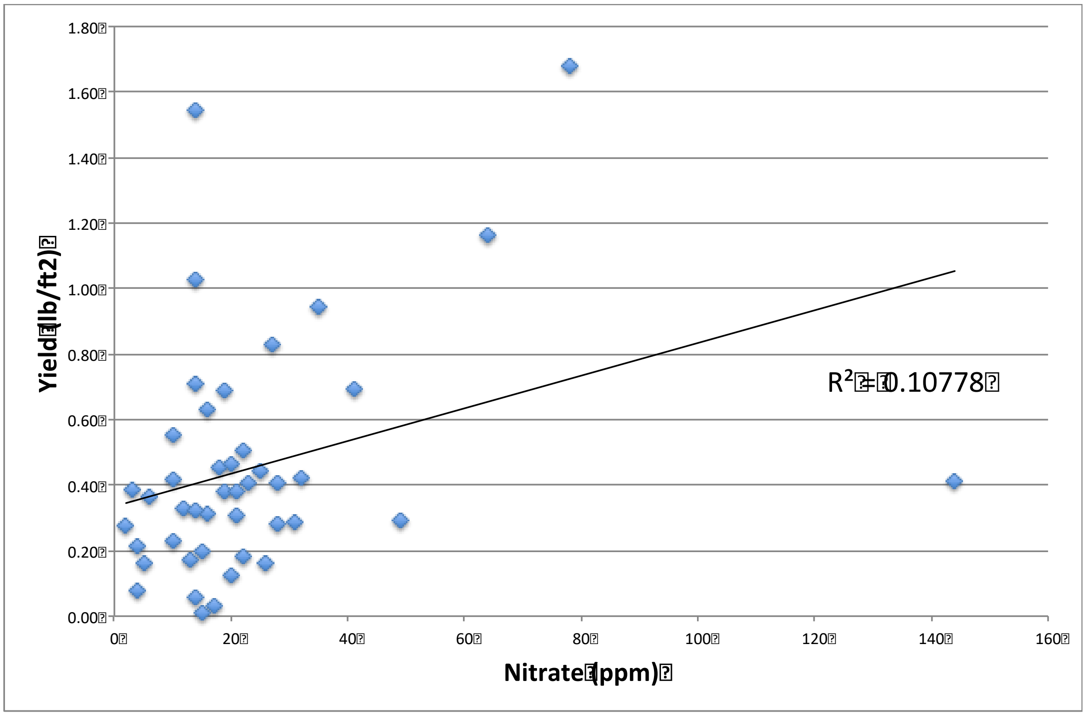


Figure 3 – Soil Phosphorous Levels Compared to Yield in Study Gardens

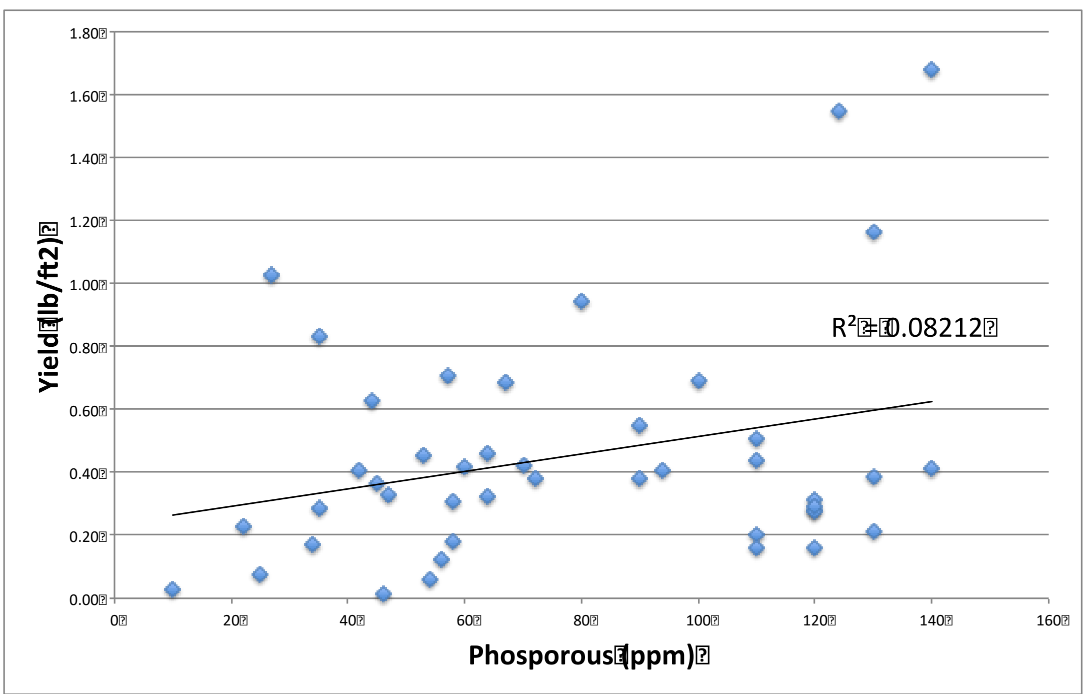
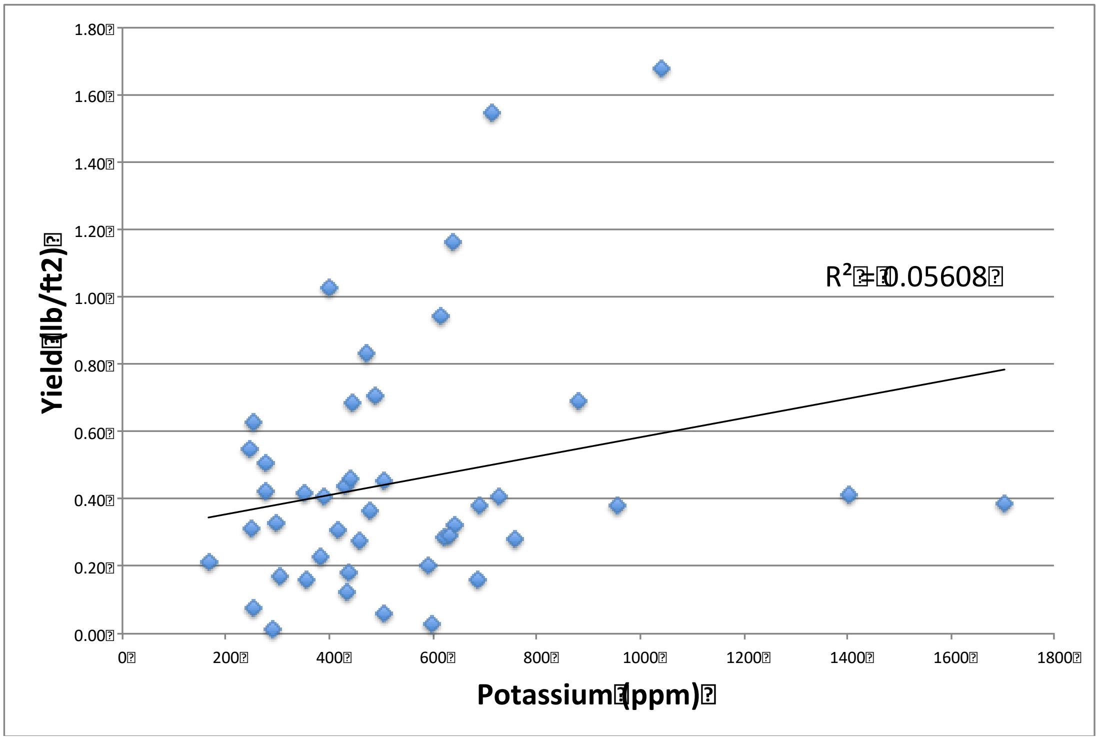


Figure 4 – Soil Potassium Levels Compared to Yield in Study Gardens



Little of the observed variance in yields can be explained by the different soil health variables plotted above. Nitrate levels have the strongest relationship with yields (R^2=0.1078) followed by organic matter (R^2=0.0714), phosphorous (R^2=0.0821), and potassium (R^2=0.0560), however these are all relatively low R^2 values.

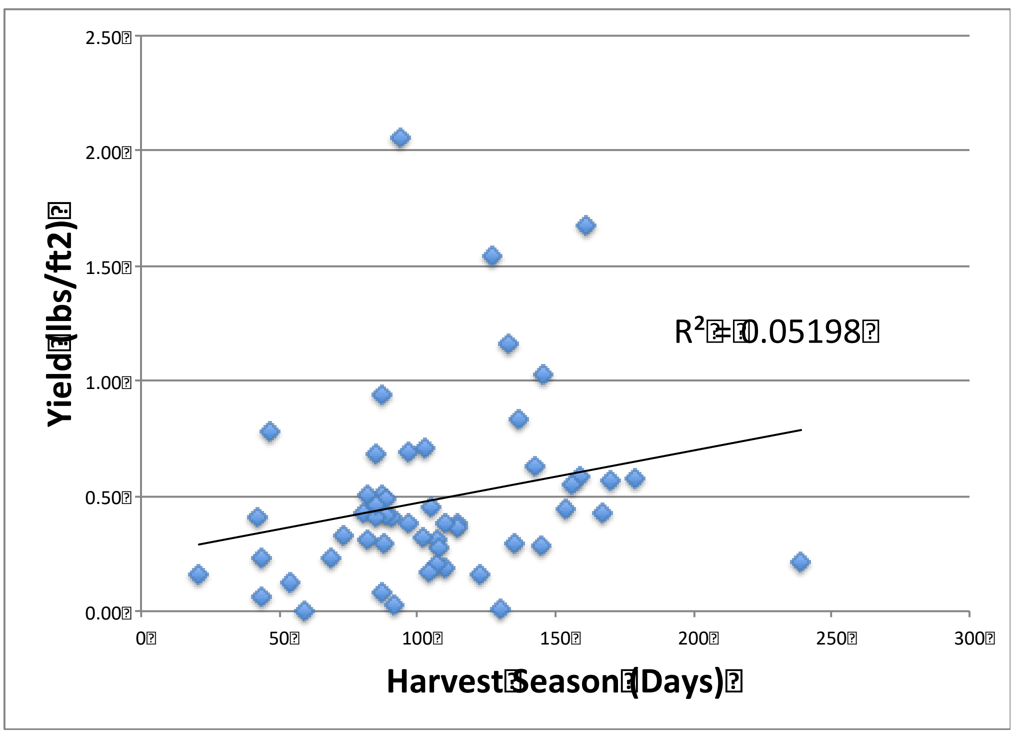
Climate and Weather Results

Climate and weather are known factors affecting crop production. Table three states GDD (our selected temperature indicator) values compared to average annual study garden yields. There is no significant relationship present, and interestingly, the least optimal year for growing temperatures was 2014 (GDD = 1081) but had higher or equivalent yields to both other years. Another factor indicating climate is harvest season. Figure 6 illustrates the relationship between individual garden harvest season length and garden yield.

Table 3 – Yields and temperature (GDD)

	GDD	Yield
2012	1220	0.44
2013	1263	0.52
2014	1081	0.52

Figure 6 – Harvest Season Length Compared to Yield in Study Gardens



3-Year Case Study

As stated earlier, a strength of our study is that it is the first in the literature to collect three consecutive years of data, including consecutive years for the same plots. Data was collected for three consecutive years for three garden plots, and for two consecutive years for 12 plots. No other published study has looked at intra-gardener variation from year to year which could be important in understanding why yields between plots and between years vary so greatly.

As a preliminary investigation, we selected a study plot that has all three years of data to better understand intra-plot variation. Outcomes for each year are shown below (Table 3). Many of the characteristics of this plot stayed relatively constant for all three years including plot area, number of harvest weeks, crop types, and number of recorded harvests. While 2014 and 2013 yields were similar, 2012 yields were significantly higher. Economic productivity measures (value per lb and value per ft^2) did not track entirely with yield. Both decreased from 2013 to 2014 as yields decreased. However, yields dropped in 2013 compared to 2014 and value per ft^2 decreased while value per pound increased

Table 4 – Three-Year Single Plot Case Study Results

Case Study Plot	2012	2013	2014
Plot Area (ft^2)	150	150	162.75
Plot Area (acre)	0.003	0.003	0.0037
Harvest Weeks	21	21	22
Recorded Harvests	127	103	124
Crop Types	11	12	15
Total Harvest (lbs)	154.2	94.3	89.64
% Eaten	57%	84%	68%
% Stored	13%	4%	29%
% Shared	29%	12%	4%
Total Harvest Value	$465.90	$324.86	$286.98
Value per lb	$3.02	$3.45	$3.20

Value per ft^2	$3.11	$2.17	$1.76
Value per acre	$135,297.00	$94,340.52	$76,811.26
Yield (lb/ft^2)	1.03	0.63	0.55
Yield: (lb/acre)	44,767.90	27,381.10	23,991.46

To further explore the characteristics of this plots harvests each year, Figures 7-9 below illustrate crops harvested ordered by their total weight. Harvests from this plot are fairly consistent both in terms of their distribution and their order. Carrots, collard greens, and mustard greens were consistently top performers by weight each year. It's surprising that more light-weight greens including collards, mustards, chard, and dill made up the majority of the harvest shares by weight as compared to heavier crops. Since harvests by weight were so relatively consistent across the three years of the case study, it's not possible to speculate whether the differences in harvested crop weights contribute to differences in yield, economic, or nutritional productivity.

Figure 7 - Case Study Plot Crops Harvested by Weight during 2014 Season

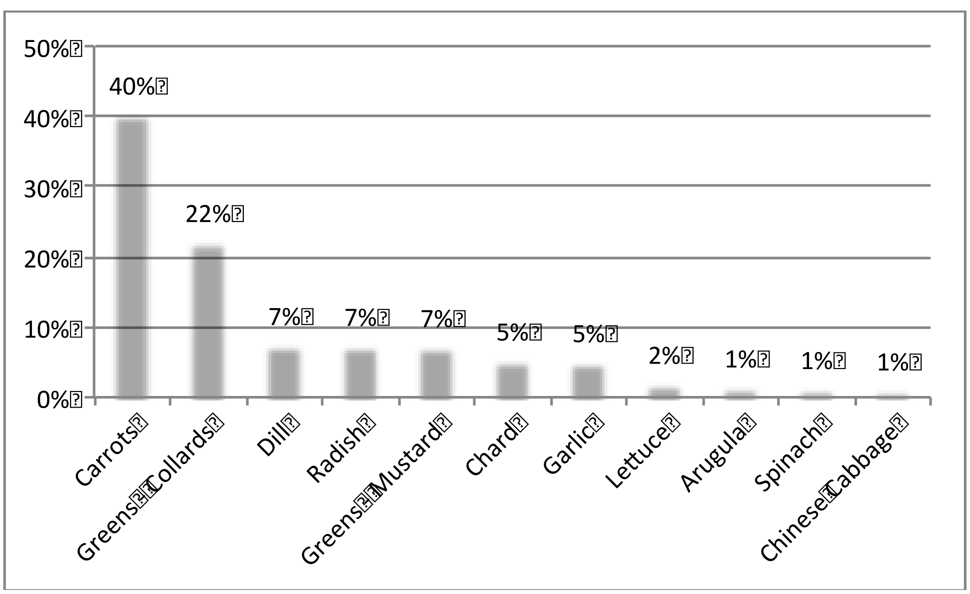


Figure 8 – Case Study Plot Crops Harvested by Weight during 2013 Season

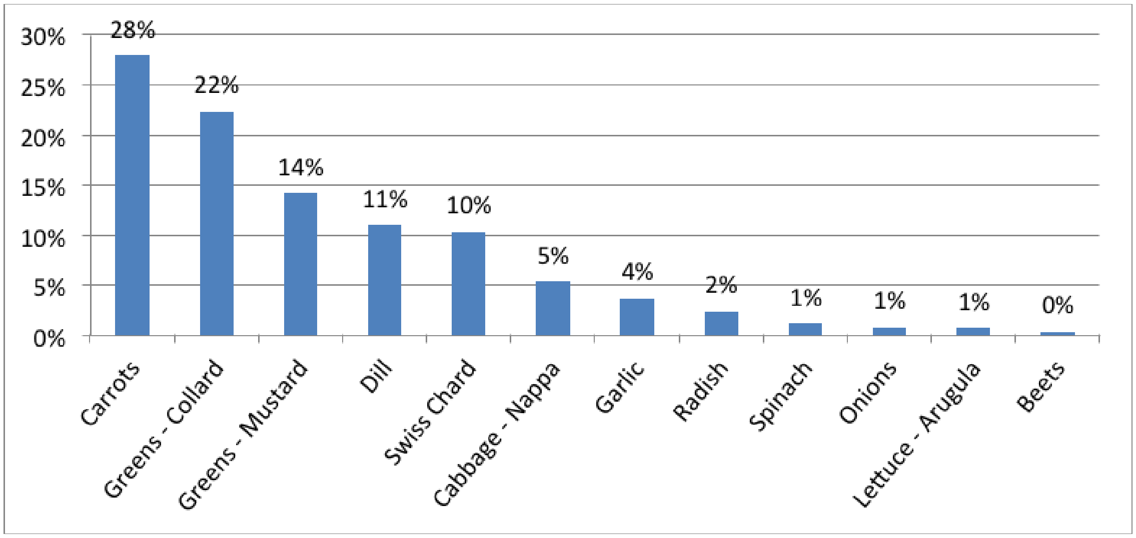


Figure 9 - Case Study Plot Crops Harvested by Weight during 2012 Season

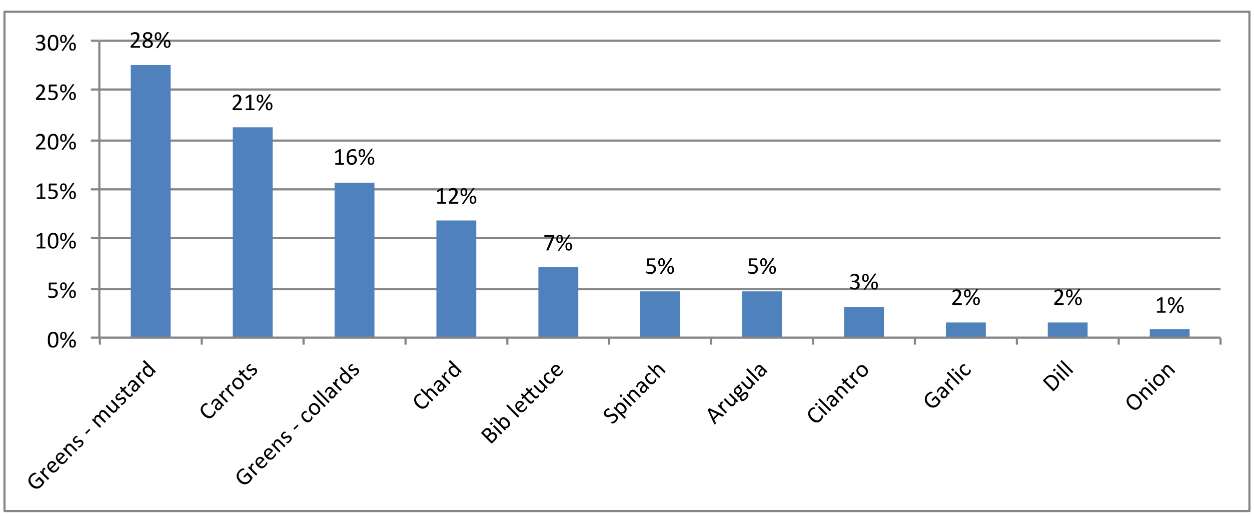
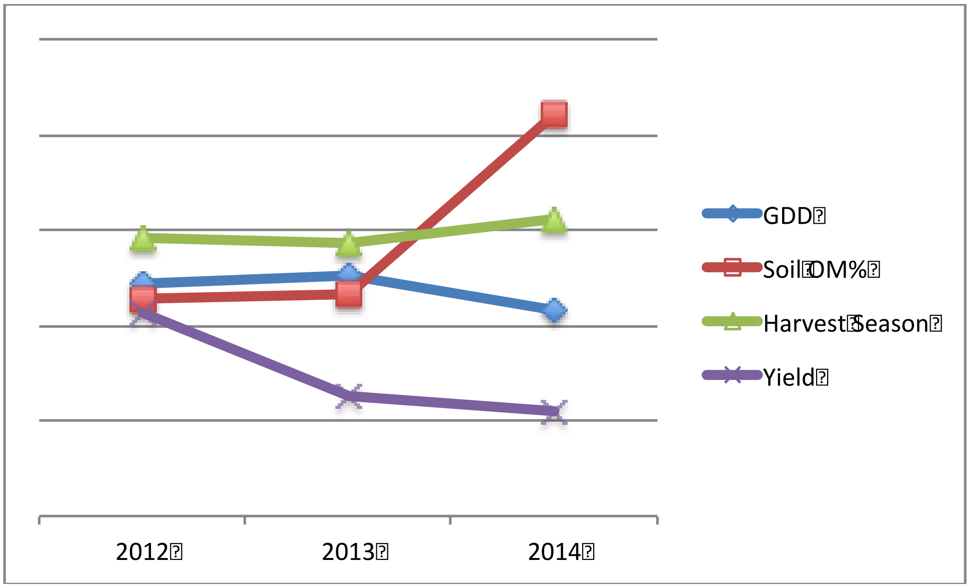


Figure 10 – Annual Variation in Yields Compared to Possible Yield Influences in Case Study Plot

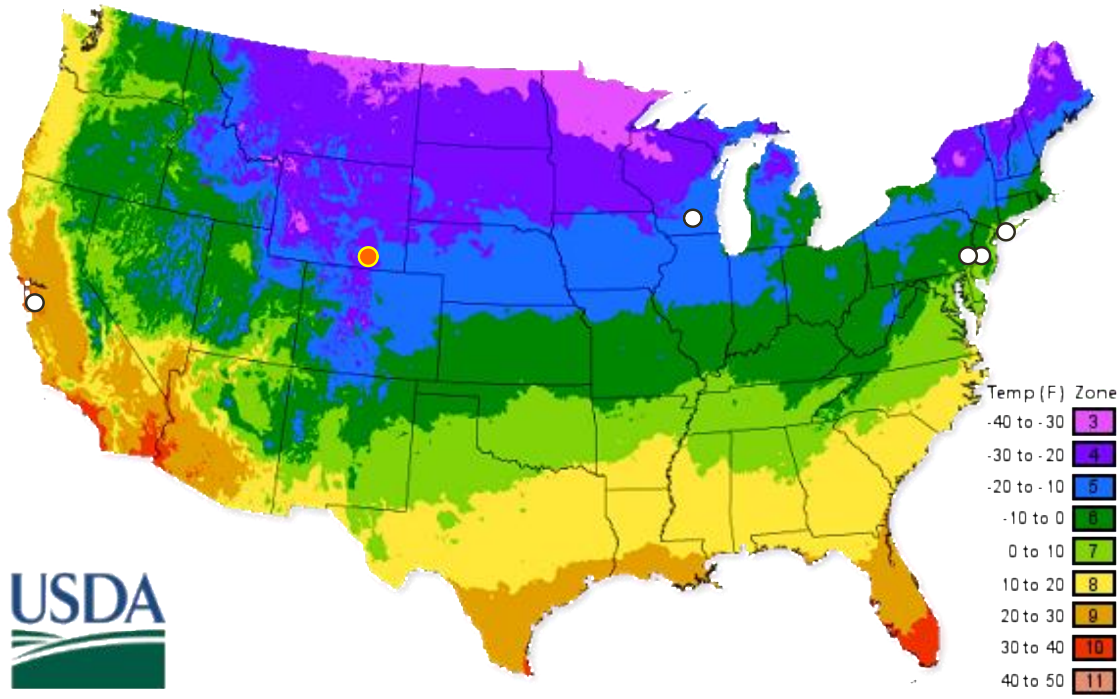


As inferred from Figure 10 above, factors that are known influences on yield did not seem to affect yield in the expected direction. It would be expected that as GDD, organic matter levels in soil, and harvest season increase, so too does yield. This relationship is not observed here, however, it is possible and likely that these factors did affect yield in the expected direction, but that correlation is masked by the many other factors that affect yield.

CHAPTER 4 – DISCUSSION

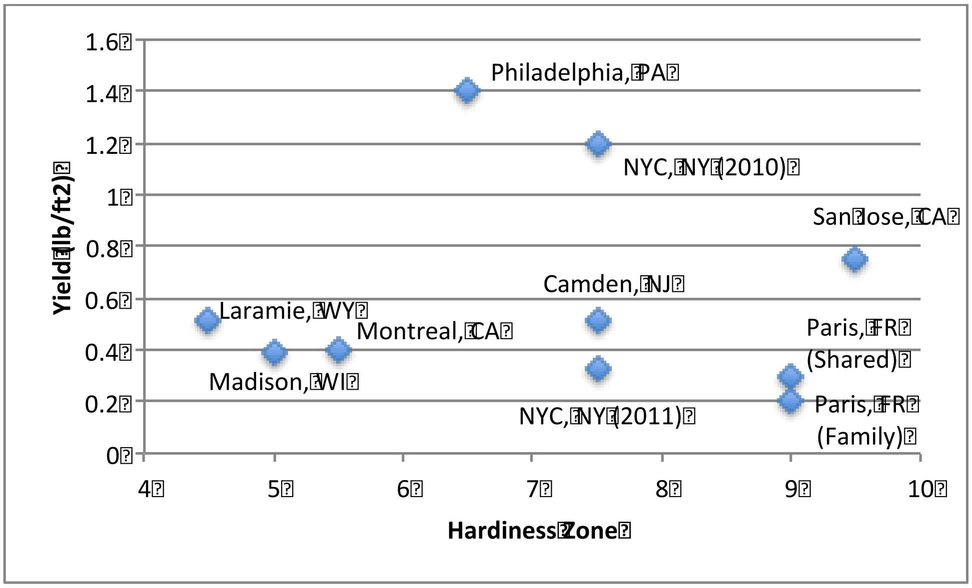
Our study adds to the small, but growing body of literature focused on the productivity of home and community gardens. Yields from Team GROW were close to the center of the average and range of yields found in similar studies despite our study site's climatic disadvantage. I compared yields and climate (using hardiness zone) of Team GROW and existing harvest studies (Table 1) to investigate whether there was a relationship between climate and yield as commonly assumed. Figure 8 illustrates US hardiness zones and location of harvest studies.

Figure 11 – Harvest Study Projects in Relation to Hardiness Zone



Note: White dots represent previous US harvest measurement study locations. Orange dot represents location of Team GROW. A harvest study was also conducted in Montreal, CA (zone 5b) and Paris, FR (zone 9a).

Figure 12 – Hardiness Zone as a Climate Indicator Compared to Yield



There does not appear to be a relationship between hardiness zone and HCG yields, which is surprising given how important growing season is perceived to be in food production. An interest for many Team GROW participants was whether results from their gardens would support or disprove the local assumption that you can't grow anything in Laramie. Yield results immediately disproved this assumption. Additionally, the diagram above illustrates how productive gardens in Laramie are compared to gardens in other areas, all of which have a more favorable climate.

An important metric for understanding the significance of HCGs is a comparison to large-scale farms where most food is grown. Yields vary by crop, but on average, conventional vegetable farms produce approximately 0.6 lb/ft^2 whereas biointensive farms (organic, high-production farming technique) produce approximately 0.83 lb/ft^2 to 0.95 lb/ft^2.[35] Another study suggests that yields for combined organic and conventional vegetable farms are approximately .67 lb/ft^2, which supports the separate conventional and organic values listed above.[36] In comparing home and community gardens to commercial agriculture, reviewed studies show that HCG yields generally approximate conventional and biointensive agriculture. Three of eight years of published study data exceeded conventional vegetable farm yields, with two of these years of data also exceeding biointensive yields (Algert, 2012: 0.75 lb/ft^2, Gittleman, 2010: 1.2 lb/ft^2, Vitiello, 2008: 1.4 lb/ft^2). Within our study, at least two plots exceeded conventional yields each year:

2012: 1.03, 2.06

2013: 0.63, 0.69, 0.69, 0.71, 0.78, 0.94, 1.55, 1.68

2014: 0.83, 1.16

Both the total yields and yield rates of HCGs found in this and previous studies suggest that gardens can make significant contributions to household food production and, even household food security. This contrasts with a common view that gardens may have myriad benefits but that food production is not one of them, for example, as typified in a 2013 journal essay that stated urban gardens provide nothing more than personal enjoyment and that it would be “misleading to pretend that urban gardening could significantly improve food security and affordability”.[37] Results from this area of study should be used as appropriate to ensure that policy is developed based on scientific research and not a misinformed narrative.

Results from Team GROW also suggest that supporting food gardening may be an effective public health intervention. Increased fruit and vegetable consumption is a well-documented benefit of HCGs, and our study quantifies HCGs’ substantial contribution to fulfilling nutritional recommendations. The fact that the average garden in our study provided approximately three-quarters of an entire year of USDA-recommended vegetable servings for a single adult is exciting and potentially useful in planning policy efforts to help address concerns of healthy diet, chronic disease, and obesity. As discussed earlier, only 20% of adults and 10% of children consume the recommended daily servings of vegetables. Furthermore, for children, 1/3 of consumed vegetables are white potatoes, largely in the form of French fries and potato chips, products rarely derived from a garden. Nutritional data from this study paired with findings from other research on increased accessibility and consumption of fresh produce strongly illustrates the potential for HCGs to be an effective public health intervention for improving diet, an important step in addressing obesity and chronic disease.

Although study gardens produced approximately 75% of the vegetable servings required per year for a single adult, the growing season is not year round, so we can infer that these nutritional benefits are probably not distributed evenly throughout the year. However, the fact that study participants stored between one-fifth and one-third of their harvests along with comments about freezing, canning and other methods of preservation in the harvest log notes column suggests that harvested produce is being consumed outside of the growing season. Harvest seasons upwards of 200 days per year as well as harvests as early as March and as late as November suggest that gardeners in this study use season-extenders such as cold frames, hoop houses, and other insulating methods which is supported by observation at garden sites.

Another potentially nutritionally meaningful measure is the diversity of crops grown in study gardens. The average garden produced between 15 and 18 different crop types each year, an important indicator of nutrient and diet diversity. Quantity and variety in fruit and vegetable consumption are equally important as different types of produce offer different essential nutrients.[38]

Results from this study elicit the question of why such large variations occur between different years and between different gardens. Many different factors including climate and weather (temperatures, freezes/frosts, extreme weather events), soil health, gardener skill and investment, crops planted, etc. affect garden productivity. It is not possible to entirely untangle the strength and possible interactions between each of these factors, however this research did some preliminary investigations into how both soil and weather may affect garden productivity.

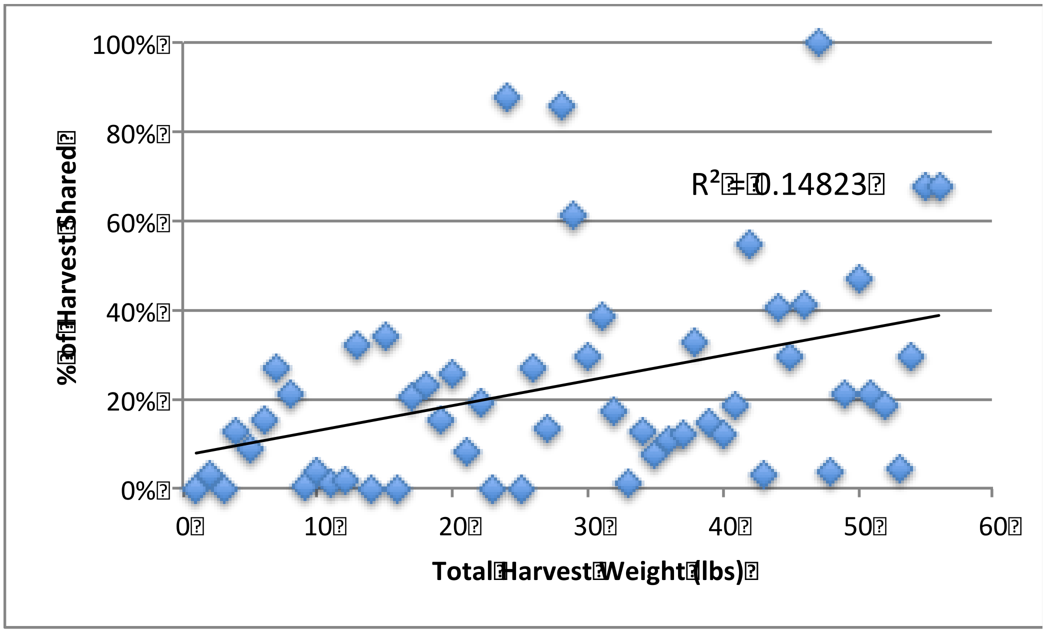
Soil affects the growth and yields of plants through the provision of nutrients. There are many important elements in soil that can limit plant yield; nitrogen, phosphorous, and potassium are the primary nutrients affecting plant growth. Deficiencies in primary nutrients as well as intermediate nutrients and micronutrients can result in reduced yields. In total, there are 15 essential nutrients soil provides to plants[39]. Instead of assessing levels of all 15 nutrients, this study used the three primary nutrients (NPK) and organic matter to measure soil health. Studies have shown a direct link between soil organic matter level and agricultural productivity.[40] The weak relationships observed between these four indicators and garden yields (Figures 1- 4) were not especially surprising given the many factors that affect crop yields.

Weather and growing season is also an assumed predictor of agricultural productivity. The challenges associated with growing food in climates with a shorter growing season have been discussed in this paper. To better understand how weather affected the outcomes in our study we compared both harvest season (as recorded by Team GROW harvest entries) and local temperatures during harvest season to garden productivity. The relationship between GDD and garden productivity in our study was insignificant with no apparent relationship between factors (Figure 5). However, there were limited data points in this assessment since growing degree days was a constant for all participants and was therefore plotted against average annual yields as opposed to individual garden yields. This suggests that temperatures (though not climate nor weather events) may have a more limited affect on garden yields than often assumed.

Harvest season was calculated for each individual and for each year using first and last harvest entries. Ideally, we would have growing season dates since harvest season does not account for the time prior to initial harvest when plants are being grown. However, harvest season is still a good indicator of growing season and the temporal boundaries of food production. While both GDD and growing season are measures of weather and climate, they are not necessarily related; harvest season is a measure of last and first frost paired with use season extending methods whereas GDD is a measure of ideal temperatures for plant production during the growing season. Length of harvest season related positively to yield as would be expected – increased time harvesting equates to increased yields. However, this relationship as illustrated in Figure 6, was weak (R^2 =0.052)

Another interesting relationship I explored was in addressing the question of whether participants with gardens that produced higher amounts of produce (as measured through weight/garden) were more likely to share their harvests as compared to participants with gardens that produced less. Figure 13 illustrates the relationship between garden harvest weights and the percent of that harvest that was shared, as opposed to eaten or stored.

Figure 13 - Total harvest weight compared to % of harvest shared



The observed relationship in Figure 13 suggests that there is a weak correlation (R^2 =0.15) between the amount of food each garden produces (measured by weight) and the percent of that harvest that is shared. We would expect that this relationship could exist as it seems that people are more likely to share if they are harvesting a greater amount of food. Overall, participants shared 30% 34% and 17% of their harvests by weight in 2012, 2013, and 2014 respectively which suggests the levels of sharing could have social and community-level implications (Table 3).

Method Applicability and Appropriateness

The different metrics reported in the body of HCG yield research raise the important question of which are most appropriate and meaningful. Weight per area unit (yield) is the most commonly used metric in this type of research, but the vegetable serving metric may be more useful in a nutritional context. The standard measurement of yield is a good general indicator of productivity. Yield however, does not account for the nutrient density of harvested crops. A plot with heavier crops such as potatoes and squash may have a much higher yield than a plot with lighter crops like leafy greens but provide a significantly different number of vegetable servings and nutritional value. On the other hand, greens may be able to have multiple harvests per season while using a smaller area. The exact relationship between yield and nutritional value per crop is unknown. For these reasons, future research focused on the health implications of HCGs should include measurements of nutritional significance in addition to yield.

There are also numerous ways to report economic productivity of HCGs. Most commonly used is a dollar value per square foot rate, however value can also be measured against weight to provide a different perspective. Economic assessments of HCGs are important for discussions on household food security, especially in low-income areas as well as neighborhoods in food deserts, which may not have access to fresh fruits and vegetables otherwise.

Future Research and Study Limitations

This research suggests several questions for future research. Though some factors that affect garden productivity were measured in this study, future research could investigate the many factors that were not measured for the purpose of this paper including gardener investment, gardener skill, severe weather events (hail, flooding), crop failure due to non-weather related reasons, type of crops grown, etc.

A number of limitations exist in this study. Error likely occurred during data collection given the tedious and demanding task of weighing and cataloging all harvested produce. It is probable that participants did not weigh every single harvested item due to the amount of labor involved, or participant confidence in estimating weight. It is also probable that at times non-edible parts of plants could have been included in the weight measurement. In order to most accurately assess economic value, participants were asked to weigh produce as would be sold at a farmers market. For this reason and others, it is likely that non-edible parts of plants could have been included in weight measurements. Since possible error includes both over- and under-estimation of harvest weights, the non-directionality of errors could mean that average findings are accurate, although there is no way of knowing.

Economic benefits of gardens did not take into account costs of inputs such as seeds, soil, water, fertilizers, etc. Therefore, the economic number values used in this paper are gross benefits, not net benefits, although as discussed, there are many non-economic and economic values (health, ecological, community) that are not incorporated into our garden production valuation. Though our sample size of gardens was large for this type of research (n=9 (2012), 33 (2013), 14 (2014) gardens) care should be taken in extrapolating our results to other communities as these results apply only to Laramie. Even within Laramie, efforts were made to recruit a diverse group of gardeners, however Team GROW is not a perfectly representative sample of Laramie gardeners.

Conclusion

Gardens are poised as an effective public health intervention for interested individuals and families. Our study specifically highlights the yields, economic value, and nutritional significance of HCGs while others studies have found health benefits such as increased physical activity and improved emotional well-being. Creating and ensuring conditions that enable individuals to make healthy choices is a defining part of successful public health interventions, and gardens do that remarkably well.

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Appendix A: Review of Published Garden Yield Studies

HARVEST YIELD PROJECTS											
			Garden Type								
Study Author	**Year(s) of data**	**Location**	**Home (n)**	**Home (lb/ft2)**	**Community (n)**	**Community (lb/ft2)**	**Education (n)**	**Education (lb/ft2)**	**Total Gardens (n)**	**Total (lb/ft2)**	**Provide Range?**
Smith & Harrington	2010	Madison, WI	13	0.4362	14	0.4219	5	0.2867	36	0.39	No
Algert et al	2012	San Jose, CA	--	--	10	0.75	--	--	10	0.75	.45 - 1.13
Farming Concrete, Gittleman et al	2010	NYC, NY	--	--	67	1.2	--	--	67	1.2	No
Farming Concrete, Gittleman et al	2011	NYC, NY	--	--	35	0.33	--	--	35	0.33	No
Vitielleo	2008	Philadelphia, PA	--	--	6*	1.4	--	--	6*	1.4	No
Vitielleo	2009	Camden NY	--	--	5*	0.51	--	--	5*	0.51	No
Pourias et al.	2013	Montreal, CA	--	--	14	0.4	--	--	14	0.4	No
Pourias et al.	2012-2013	Paris, FR (Family Gardens)			19	0.2			19	0.2	
Pourias et al.	2012-2013	Paris, FR (Shared Gardens)			18	0.3			18	0.3	

Appendix A: Review of Published Garden Yield Studies

Economic						
Prices Used	**Estimated Value**	**Crop Area (ft2)**	**$/ft2**	**Notes**	**Extrapolation**	**Methodology Notes**
10 market visits over the course of the growing season and across several market venues. Venues included two conventional grocers, a specialty grocer (organic products), a food cooperative, and a farmers' market	$9,440,806	6,477,398	$1.46	Also measured Calories, Percent of Caloric Need, and Percent of total food sales.	Extrapolated weight, gross and net market value, and caloric value from 36 test plots tended by citizen scientists to all of Madison Urban Area (MUA)	Used relationship established in our regression analysis between garden presence and homeownership as well as average garden size to estimate the total area under production within study area. Estimated the agricultural productivity of the study area based on the production means from the citizen-science test plots. The result is an estimate of the total gross value, net value, and calories produced through CFP within the MUA.
Bureau of Labor Statistics for the western region 2012 for tomatoes, lettuce, peppers, and broccoli. Other vegetables - local grocery store in the San Jose area - 11/2012.	$4,678.20	4,140	$1.13	Use and discussion of citizen scientists. Results indicate community garden practices more similar to biointensive high-production farming, producing 0.75 lb vegetables/sq ft, rather than conventional agricultural practices, producing 0.60 lb/sq ft	None	Documents vegetable output (lb/ft2) and cost savings. 83 gardeners completed background survey ($5 incentive). Subset of 10 gardeners (rep of larger group) completed harvest measures ($40 incentive - $20 at beginning of season, $20 at end of season)
Whole Foods and local urban farms to account for the premium that local, organic food typically demands	$214,060	74,052	$2.89	Year 1 (2010) only included fruits and vegetables. Year 2 (2011) included herbs and fruit trees.	Gardeners either weighed produce or did crop counts. Weight measurements extrapolated from 30 gardens to 67 gardens.	Gardens interested in weighing produce receive a small kitchen scale and printed forms on which they record pounds per crop and the number of plants per crop for the duration of the growing season. Those interested in counting plants record the number of plants per crop and dimensions of areas under production for the entire garden.
Whole Foods and local urban farms to account for the premium that local, organic food typically demands	$47,000	40,946	$1.15	Year 2 (2011) also included school gardens which are often dormant when school isn't in session.	Gardeners either weighed produce or did crop counts. It was not disclosed how many gardeners did the weight measurement, though it wasn't all 35 gardens. The data from those that did collect harvest weight was extrapolated to the 35 gardens.	Gardens interested in weighing produce receive a small kitchen scale and printed forms on which they record pounds per crop and the number of plants per crop for the duration of the growing season. Those interested in counting plants record the number of plants per crop and dimensions of areas under production for the entire garden.
Farmer's Market	$4,860,364	1,454,890	$3.34	6*: Harvest measures tracked at 6 community gardens. Actual number of plots or gardeners unknown.	Extrapolated to 33.4 acres (226 gardens) (Philadelphia)	Weighed harvest by crop. Food Producing gardens measured area (square footage) under production, water sources, evidence of support organizations, and other data. At smaller sites, tallied entire area under production by crop. At larger sites, a representative sample of four plots or, at the largest gardens, 10% of all plots were tallied by crop.
Farmer's Market	$64,756	60,621	$1.07	6*: Harvest measures tracked at 6 community gardens. Actual number of plots or gardeners unknown.	Extrapolated to 30,836 lbs / 48 gardens / 164,472 sf (Camden)	Total area of the garden property, water sources, presence of fruit trees, and other data.
N/A	N/A	N/A	N/A	Quantitative and qualitative data tracked. Measured yield, produce destination, types of crops grown, and use of space in plots. Comprehensive Interviews with gardeners.	None	Gardeners interviewed twice during season. Harvest records include crop type, date, quantity (weight) use of crop, and destination of crop. Plots were monitored monthly with following recorded: newly planted crops and area, growing plants, harvests ain process.

Appendix B: Team GROW Harvest Measure Form

Gardener Name: ______________________________

Plot location (if tracking more than one plot): ______________________________

2014 Team GROW Harvest Measure Form

Team Grow (Gardener Researchers of Wyoming) is a collaboration of Feeding Laramie Valley (FLV), the University of Wyoming Food Dignity Initiative (FD, www.fooddignity.org) and gardener-researchers of Albany County, WY.

Please give completed electronic or paper copies to Shannon Conk or Livy Lewis
sconk@uwyo.edu, 9702370428, Feeding Laramie Valley Building

INSTRUCTIONS: Weigh each time you harvest and enter data in ounces please. Tare scale for any container used. Remove excess dirt and weigh in form you would find at a farmer's market (e.g. carrots usually include stems and leaves). For crop type, you can track particular varieties (e.g. red leaf lettuce) or summarize by group (e.g. "salad greens"). Under food use, estimate percent. Notes are optional.

Date	Crop Type	Weight (ounces)	Food Use (% estimate)			Notes
			Eat	Store	Share	