OVERCOMING BARRIERS IN URBAN AGRICULTURE TO PROMOTE HEALTHY EATING ON COLLEGE CAMPUSES

by

Kyle Richardville

A Thesis

Submitted to the Faculty of Purdue University
In Partial Fulfillment of the Requirements for the degree of

Master of Science

Department of Ecological Sciences and Engineering
West Lafayette, Indiana
December 2020

THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Dr. Lori Hoagland, Chair
School of Agriculture

Dr. Aaron Thompson
School of Agriculture

Dr. Andrew Flachs
School of Liberal Arts

Approved by:
Dr. Linda S. Lee

Dedicated to the millions worldwide who face food insecurity. You are not forgotten.

ACKNOWLEDGMENTS

I would like to thank Dr. Lori Hoagland for not only the time and effort she dedicated toward my education, but also her positive influence in my life as a determined researcher with a heart committed to making positive change in the world.

I would also like to thank Dr. Andrew Flachs and Dr. Aaron Thompson for their continuous help throughout my Master's education. You two have been enormously helpful and have also shown me a good example of how research can positively change the world in which we live.

I would be very remiss if I failed to thank the members of the Hoagland lab that helped me along this journey. Whether it was helping perform assays, harvesting tomatoes during the summers or just being a great friend during stressful times, each act of friendship helped encourage me to be my best and is very much appreciated. In addition, I would like to thank Chris Adair of the Purdue Student Farm and Niki de Armond of the Purdue Agronomy department for their help with field preparation, maintenance and N assay work.

Finally, I would like to thank my family for instilling in me a spirit of excellence that has proved invaluable throughout my Master's journey. The love and support you've shown me my whole life is truly a blessing. To my friends, new and old, thank you as well for helping me through the tough times and celebrating the good times. *Gloria in Excelsis Deo.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Food insecurity and nutrition are two of the biggest challenges facing our society. Urban agriculture can help address these challenges, though lack of awareness about opportunities for engagement and degraded soils are two barriers that could prevent people from realizing the benefits that these operations can provide. Soils in urban areas are often highly degraded due to development activities and lack the structure and microbial life needed to sustain healthy, productive plants. Many lifelong habits such as healthy eating and engagement in community gardening are best established during young adulthood. Graduate school is a particularly unique time period, as many students are living on their own for the first time with modest incomes and some have young families that are particularly vulnerable to food insecurity. Consequently, the first objective of this project was to identify which barriers, if any, Purdue graduate students face when purchasing and consuming fresh produce and participating in local urban agriculture initiatives as Purdue's campus and much of the surrounding area are characterized as food deserts by the USDA. We also sought to determine how the COVID-19 pandemic influenced food access and motivations for healthy eating and community garden engagement. To answer these questions, we distributed a voluntary 33 question online Qualtrics® survey to all Purdue graduate students via mass email blast. Results indicate that many Purdue graduate students face individual and structural barriers to accessing fresh fruits and vegetables. International respondents, in particular, were particularly vulnerable to structural barriers. Not having access to a personal vehicle appears to be the primary predictor of who was most vulnerable, especially during the pandemic. Results also indicate that students are interested in participating in local urban agriculture initiatives, but most are unaware of their existence. Students indicated that e-mails were the best method for increasing awareness and engagement. The second objective of this study was to determine whether leaf mold compost could improve the health and productivity of degraded urban soils. In addition, we aimed to determine whether the leaf compost could better support a beneficial microbial inoculant to further enhance crop productivity, as well as the extent to which plant genotype moderates these beneficial plant-soil-microbial relationships. To answer these questions, leaf compost was obtained from a local grower and applied to experimental plots at the Purdue University Farm. Two tomato varieties, Wisconsin 55 and Corbarino, were inoculated with *Trichoderma harzianum* T-22 or a sterile water control, and transplanted into the field trials.

Survival following transplanting, vigor, disease ratings and the yield and quality of tomato fruit were quantified over the course of two growing seasons. Results indicated that several measures of soil health were significantly increased in compost-amended soils and the health and productivity of tomato plants greatly improved. The microbial inoculant dramatically reduced transplant stress, especially in Wisconsin 55. Other more subtle differences among the tomato varieties indicated that urban agriculture systems could be improved through varietal selection. These studies highlight the fact that graduate students are not immune to food insecurity and proper nutrition and they are interested in connecting with urban agriculture initiatives to address these challenges. Pairing of the two groups could prove to be a successful mutualistic symbiosis as graduate students provide the enthusiasm and manpower that urban gardens need while urban gardens offer access to low-cost fresh produce that many graduate students desire. Leaf mold compost can aid in these initiatives by providing a cost-effective approach to improve the health and productivity of urban soils and crops, while at the same time providing further benefits such as reduced accumulation of valuable carbon sources in municipal landfills. Results like these provide stark evidence that agriculture, particularly urban agriculture, can continue to improve access to nutritious foods through green initiatives and innovations.

CHAPTER 1. INTRODUCTION

Food insecurity rears its ugly head in most every neighborhood across the globe. Unfortunately, some neighborhoods experience harsher levels of it compared to others. The roots of food insecurity can vary greatly neighborhood-to-neighborhood. Two factors most important for determining food security in an area are: access to establishments that serve unhealthy, calorie-dense foods and access to establishments that serve healthy, nutrient-dense foods. Oftentimes, the two factors negatively correlate. Residents of lower socioeconomic neighborhoods are particularly at risk for food insecurity as many of these neighborhoods are inundated with fast food restaurants and corner stores that serve cheap, calorie-dense foods while lacking adequate access to establishments that serve healthy foods (Ammerman, 2012). The proceeding thesis chapters focus on the latter issue: lack of access to healthy foods. The United States Department of Agriculture (USDA) has identified criteria concerning adequate access to nutritious foods and areas that do not meet these criteria are deemed “food deserts”. Unfortunately, college campuses are not impervious to food security issues and some are classified as food deserts. Although Purdue University is one of the nation’s top agricultural universities, much of its campus and surrounding areas fall under the category of food deserts. Many studies have been conducted to observe the effects that campus food deserts have on the students that attend these places of higher learning. However, the overwhelming majority of these studies look solely at undergraduate student populations. For these reasons, a survey was created to inquire the Purdue graduate student population about any barriers they may be forced to overcome when purchasing nutritious foods considering the local food landscape. Prior to the public release of the survey, the COVID-19 pandemic forced many disruptions to the local community and questions were added that asked how this monumentally difficult circumstance affected food purchasing and consumption patterns. The survey concluded with a section of questions regarding community garden knowledge and participation. These were included because implementation and utilization of community gardens in areas lacking access to nutritious foods has proven a successful method for increasing access and fresh fruit and vegetable intake among residents (Barnidge et al., 2013; Claieborn 2012). Local community garden leaders have expressed a need for volunteers so a great opportunity could present itself if the majority of respondents report difficulties accessing healthy foods, but do not utilize the services of local community gardens.

Although community gardens are trying their best to help alleviate food insecurity in some areas, rising demand for food in urban areas is projected to increase steadily worldwide as the century progresses. In addition, climate change and the depletion of soils threatens the production capabilities of both urban and rural farming operations. Technological innovations in the agricultural field have helped the human race dodge mass starvation as recently as the 20th century. 21st agricultural innovations are needed as well, but scientists can no longer ignore the direct and indirect effects that these innovations will have on the environment. Two green technologies that show great potential to increase yields while decreasing negative environmental impacts and improving soil health are microbial inoculants and leaf compost soil amendments. Specifically, inoculants created with the species *Trichoderma harzianum* have shown the potential to increase a plant's induced systemic resistance (ISR), thus decreasing the need for producers to purchase and apply potentially harmful pesticides to their crops. ISR effects by *T. harzianum* inoculations have proved successful from select genotypes in a controlled greenhouse setting, but have yielded unpredictable results in outdoor settings. Because *T. harzianum* is a fungal species, we hypothesize that transforming the soil environment into one that is more conducive to fungal growth and survival will increase the efficacy and predictability of *T. harzianum* inoculations in the field. Leaf compost amendments were chosen to accomplish this task as leaves contain a high C:N ratio and fungal communities prefer to grow in high carbon environments. Leaf compost amendments also benefit the soil by providing organic matter, increasing water holding capacity and improving soil tilth while at the same time increasing crop yields (Naikwade, 2014) and decreasing year-to-year yield variability (Maynard and Hill, 2000). Plant health status and fruit yields of two genotypes of tomatoes, Corbarino and Wisconsin 55, were observed in order to distinguish the effect that genetics plays both from the inoculations and leaf compost amendments.

Agricultural innovation in the 21st century is desperately needed as producers are tasked with feeding more and more mouths from the fruits of plants grown in soils that have largely been stripped of their nutrients and microbial life on a planet whose climate is changing in dramatic fashion. Improving access to nutritious food for vulnerable urban communities through the use of microbial inoculants and leaf compost amendments on its production sites are two examples of how agriculturalists worldwide are planning to accomplish the prodigious tasks facing them and humanity as a whole.

1.1 References

Ammerman, M. (2012). Accessing nutritious food in low-income neighborhoods. *NC Med J.* 73: 384-385

Barnidge, E. K., Hipp, P. R., Estlund, A., Duggan, K., Barnhart, K. J., & Brownson, R. C. (2013). Association between community garden participation and fruit and vegetable consumption in rural Missouri. International Journal of Behavioral Nutrition and Physical Activity, 10(1), 128. https://doi.org/10.1186/1479-5868-10-128

Claieborne, S. (2012 April 22) Practicing Resurrection: Turning Vacant Lots Into Gardens in Philadelphia. *Huffuington Post.* Retrieved from https://www.huffpost.com/entry/practicing-resurrection-t_b_1443621

Maynard, A. A., &; Hill, D. E. (2000). Cumulative Effect of Leaf Compost on Yield And Size Distribution in Onions. Compost Science &; Utilization, 8(1), 12-18. doi:10.1080/1065657x.2000.10701744

Naikwade, P. (2014). Effect of litter compost on yield and nutrient content of Zea Mays L. *Sci. Res* Rep. 4(1):79–84

CHAPTER 2. SURVEY OF PURDUE GRADUATE STUDENTS

2.1 Introduction

Foods consisting of excess sodium, saturated fat, refined grains, and calories from solid fats and added sugars are staples of the Standard American Diet (or SAD, as it is appropriately named) (*2015-2020 Dietary Guidelines for Americans*, 2015)**.** The increasing consumption of calorie-dense foods and decreasing consumption of nutrient-dense foods is an indication that the nation's diet in crisis (Krebs-Smith et al., 2010). However, many disparities exist in the overall quality of diets between different groups of Americans. For example, Americans of lower socioeconomic status tend to consume a poorer overall quality of diet than those of higher socioeconomic status (Appelhans et al., 2012; French et al., 2019; Pechey & Monsivais, 2016; Shahar et al., 2005; Wang et al., 2014). This begs the question: Why do lower socioeconomic groups engage in lower quality dietary habits? Could it be because individuals living in lower socioeconomic classes inherently make poorer health decisions? Studies do show that individuals hailing from lower socioeconomic groups exhibit increased levels of risky health behaviors (Siashpush et al., 2009; Karriker-Jaffe et al., 2013; Payne et al., 2017). However, asking the question "why do these individuals make poorer dietary choices?" gets more to the heart of the issue. Research shows time and again that many "poor or low-income residents often have fewer resources that promote health (e.g., full service grocery stores)" (Bell et al., 2013; Collins et al., 2016.; Evans & Kantrowitz, 2002, Mowen, 2010). A lack of basic access to affordable, nutrient-dense foods that some neighborhoods experience across the United States results in what many experts refer to as a 'food desert'. Food deserts are named as such because "the search for and acquisition of nutritious foods is not easily accomplished", just as in a physical desert (Rogers, 2015). Socioeconomic status among residents appears to be a reliable predictor of food desert prevalence regardless of whether the environment is urban, very dense urban or rural (Dutko et al., 2012). However, it is important to note that living in a food desert does not necessarily mean those living within it are deprived of access to the appropriate number of calories recommended as part of a healthy diet. Cheap, energy-dense foods are readily accessible in food deserts at establishments such as fast food restaurants or convenience stores (Ammerman, 2012). This lack of access to healthy foods, paired with higher costs of foods contained in a healthy diet (Kern, 2017) and transportation issues among individuals living in poverty (cdc.org), begins to paint a clear picture that barriers to healthier foods are harder to overcome in lower socioeconomic populations.

Public health officials, nutrition program designers and policymakers spend an enormous amount of time and money trying to understand barriers that individuals face when purchasing and consuming healthy foods. In 2008, Congress passed the 2008 Food, Conservation and Energy Act. This bill tasked the USDA with massively increasing their efforts to "assess the extent of areas in the United States where people have limited access to a variety of healthy and affordable food" (The USDA subsequently published "*Access to Affordable and Nutritious Food: Measuring and Understanding Food Deserts and Their Consequences* (ver Ploeg, 2009), which found that "23.5 million Americans live in low-income areas that are further than 1 mile from a large grocery store or supermarket, and that 11.5 million of these people have low incomes themselves.". In 2010, the United States government announced the inception of the Healthy Food Financing Initiative (HFFI) as part of the "Let's Move!" public health campaign to help overcome this challenge. In 2019, the USDA estimated that 19 million people, or 6.2% of the US population, live in tracts of land that are low-income and low access, meaning they and are more than 1 mile (urban) or 10 miles (rural) from the nearest supermarket" (usda.gov). The USDA also estimated that "2.1 million households, or 1.8 percent of all households, are in low-income and low access census tracts, are far from a supermarket and do not have a vehicle"(usda.gov). The HFFI recognizes that increased access to grocery stores and other healthy food retailers has the potential to provide enormous economic benefits by creating and retaining new jobs, generating tax revenue and promoting foot traffic to support other stores and the local economy. Program developers for the HFFI reviewed more than 300 cases that show increasing access to fresh and healthy foods "improves eating habits and can contribute to positive health outcomes, including decreased risk for obesity and diet-related diseases." Results from separate studies support this comment (Bradford et al., 2019; Michimi & Wimberly, 2010; Costa et al., 2019). Nevertheless, there is mounting evidence that observable improvements in the diets of residents are not found when solely introducing a supermarket or other healthy food retailer into a community. For example, Cummins et al (2014) investigated fruit and vegetable intake patterns after the opening of a new supermarket in a Philadelphia food desert. Interestingly, the sample contained a high proportion of university students. The team of researchers discovered that residents exhibited only a moderately improved perception of their food access and only 26.7 percent of the neighborhood's residents utilized the new supermarket as their primary store. Moreover, the new supermarket did not significantly influence mean residential BMI or fruit and vegetable intake after six months of opening. The research project was part of a pilot study with a small sample size, but its results seem to contradict a widely-held belief that consumers will naturally increase fruit and vegetable consumption if they are granted access. Researchers in Illinois echoed this conclusion in their survey of a low-income, primarily minority neighborhood in Chicago, Illinois where they concluded that, "simply increasing availability may not yield beneficial change when characteristics of the shopping context are ignored" (Blitstein et al., 2012). One study investigating the effects of a new Pittsburgh supermarket funded by the HFFI even found that consumption of fruits and vegetables declined after the new supermarket opened, which was in congruence with a comparison neighborhood that did not receive a new supermarket (Dubowitz et al., 2015). One reason may be that simply changing dietary behaviors is simply very difficult as physiological processes like the human's innate preference to sweet and salty foods and psychological processes like learned food preferences steer our natural tendencies towards what is most tasty, what is most convenient and what is most comfortable (LaCaille et al., 2013).

This newfound knowledge that better dietary outcomes aren't always observed when a supermarket is introduced makes for increasingly complex circumstances when thinking of solutions. Even so, the situation does appear to be improving. In 2018, 11.5 percent of Americans experienced food insecurity at some point during the year. These numbers are lower than the 11.8 percent of Americans that experienced food insecurity in 2017 (usda.gov). However, the recent COVID-19 global pandemic has caused economic problems of historical proportions in the United States and the extent of the pandemic's effects on food security remain to be seen. According to the Bureau of Labor Statistics, total unemployment rates of Americans 16 years and over ranged from 3.7 percent in July 2019 to 14.7 percent in April 2020, and 10.2 percent in July 2020 (Figure 2.1).

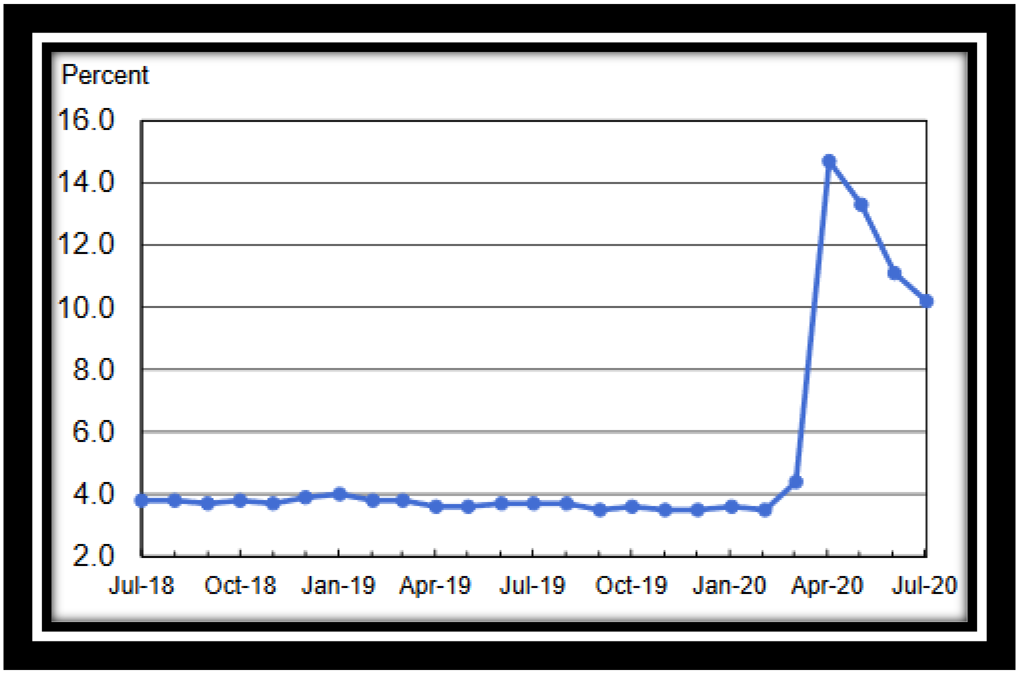


Figure 191. Nonfarm, Seasonally Adjusted, Unemployment rate for July 2018-July 2020 (American Bureau of Labor Statistics)

Feeding America's "Map the Meal Gap" study estimated values for increased prevalence and abundance of food insecurity based on increases in unemployment and poverty rates primarily caused by coronavirus-response measures. This study projected food insecurity values for three scenarios (see Table 2.1; Figure 2.2). Scenario A represents the same changes to unemployment that the United States experienced one year after the Great Recession of 2008. 3.3 million Americans are added to the list of food-insecure individuals under this scenario. Scenario B represents the same changes to unemployment that the United States experienced two years after the Great Recessions of 2008. Around 9.9 million Americans became food-insecure at this time. Lastly, Scenario C represents the most severe possibility with a 7.6 percentage point increase in unemployment rates. At this rate of unemployment, 17.1 million Americans are added to the list of food-insecure individuals.

Table 191. Map the Meal study predicted food insecurity rates based on projected changes to unemployment and poverty rates (Feeding America)

	Scenarios		
	A	B	C
Unemployment rate increase (% pts)	1.1	4.5	7.6
Poverty rate increase (% pts)	1.5	2.6	4.8
Food insecurity rate increase (% pts)	**1.0**	**3.0**	**5.2**
Increase to number of food-insecure individuals	**3.3 million**	**9.9 million**	**17.1 million**

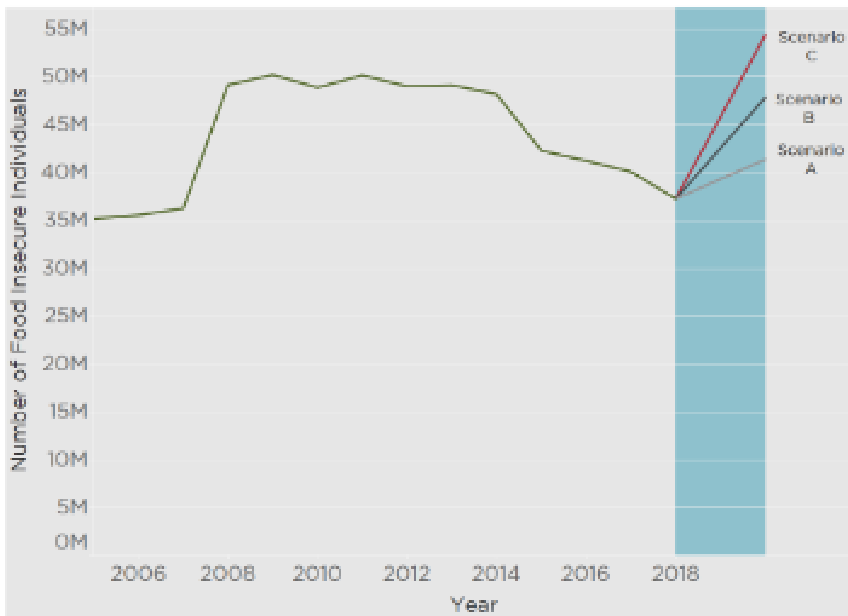


Figure 192. Feeding America's Map the Meal food insecurity trends and projections based on projected changes to unemployment and poverty (Feeding America)

While most studies investigating food security challenges associated with food deserts and COVID-19 focus on low-income tracts of land, college campuses such as Purdue University could also be at risk. The Economic Research Service (ERS) branch of the USDA has developed a Food Access Research Atlas, which spatially delineates areas satisfying criteria of a food desert. The three main criteria are: access to sources of healthy food, individual-level resources that may affect accessibility, and neighborhood level-indicators of resources. Much of Purdue University's campus and surrounding areas are designated food desert regions. Most of the students attending Purdue University's West Lafayette campus live on or near the university. Graduate students are no different as indicated by Purdue University's "Graduate Student Housing" webpage which recommends Purdue Village as an on-campus housing option and Black Bird Farms II as a viable off-campus option. The Cottages on Lindberg are also a popular place of residence for many graduate students. Screenshots from the USDA's Food Access Research Atlas (see Figure 2.3; Figure 2.4) indicate that these three popular student neighborhoods, Purdue Village, Black Bird Farms II and the Cottages on Lindberg, are all within the confines of what are considered food deserts.

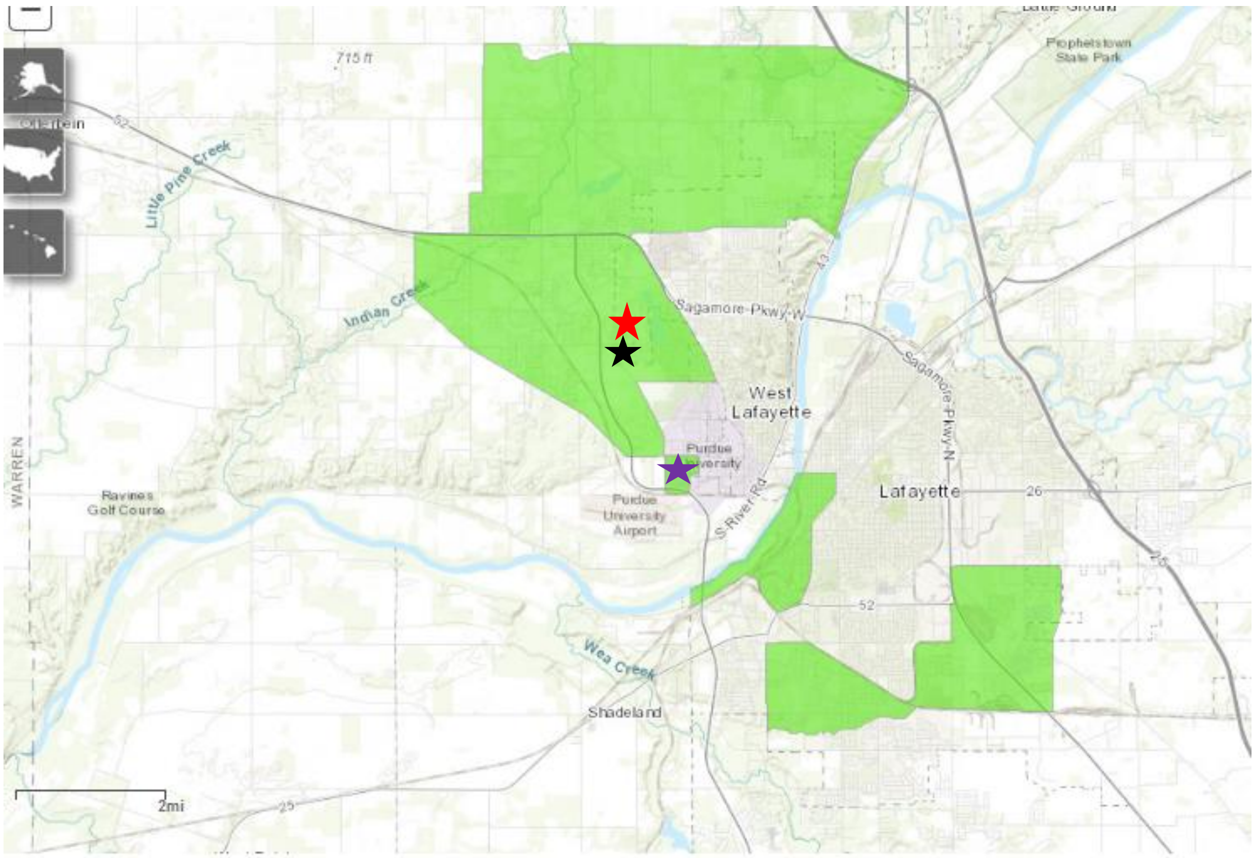


Figure 193. The locations of Purdue Village (purple), Black Bird Farms II (black) and the Cottages on Lindberg (red) on the map of low-income census tracts where a significant number or share of residents is more than **1 mile** (urban) or 10 miles (rural) from the nearest supermarket (USDA)

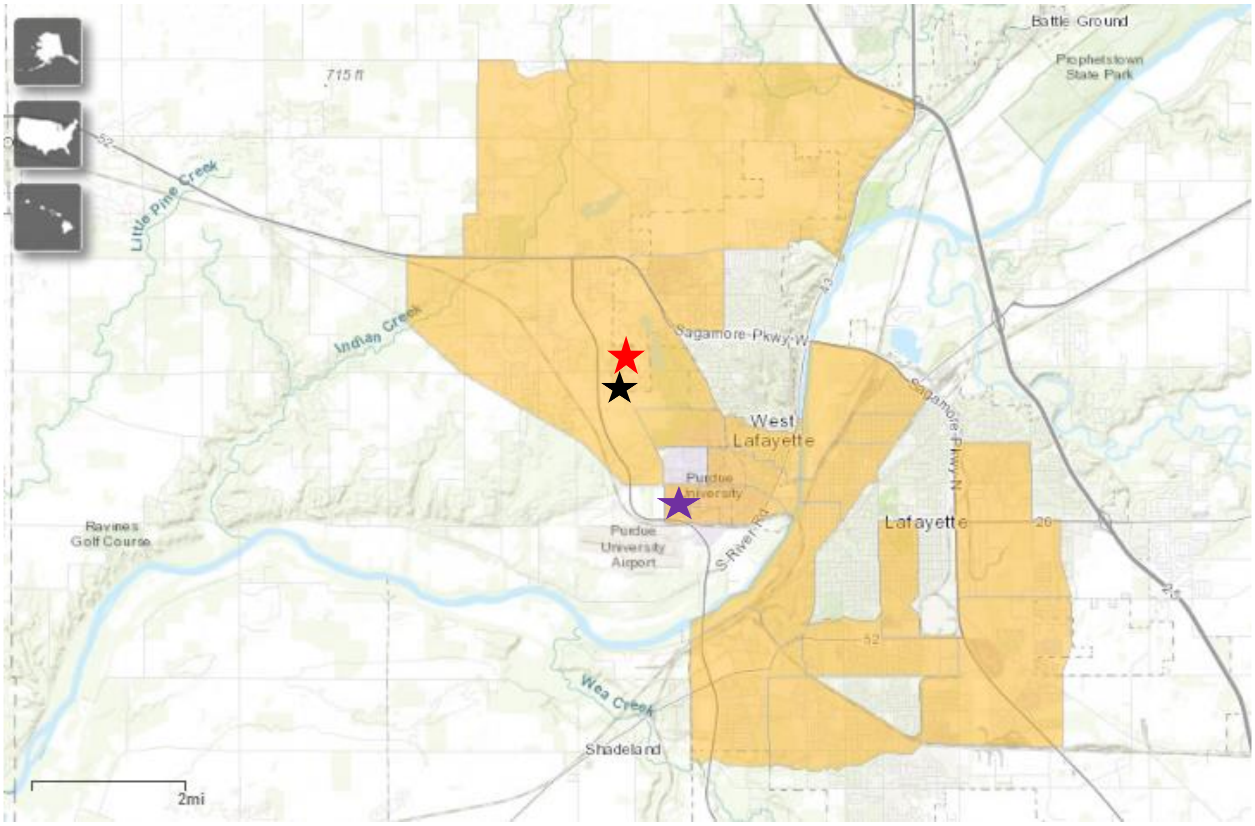


Figure 194. The locations of Purdue Village (purple), Black Bird Farms II (black) and the Cottages on Lindberg (red) on the map of low-income census tracts where a significant number or share of residents is more than **1/2 mile** (urban) or 10 miles (rural) from the nearest supermarket (USDA)

Understanding the geography of food landscapes is important because living within a food desert is likely to influence dietary behaviors, as supported by Albert Bandura's social cognitive theory (SCT). Reciprocal determinism is the primary concept of the SCT and is defined as the "dynamic and reciprocal interaction of person (individual with a set of learned experiences), environment (external social context), and behavior (responses to stimuli to achieve goals)". The SCT is unique in its focus on *maintenance* of a behavior, rather than solely addressing factors that influence *initiation* of a behavior. Understanding the social and geographic environment Purdue University graduate students find themselves interacting with is a major goal of this research project. However, the SCT investigates individual psychological choice as it is influenced by reciprocal determinism. We are interested in discovering to what degree the food landscape influences individual choice and behavior. Food deserts, however, are very complex and often do not even allow the individual to make a choice as the barriers to accessing fresh produce is too large to overcome. Thus, this exploratory research endeavor is seeking to discover the extent to which the food landscape barriers affect individual nutritious food behaviors and whether or not these barriers are too large to overcome for some or all of the research participants such that their ability to choose has been stripped away from them.

Purdue University's Dining & Culinary webpage states that, "Eating well at Purdue University is easy with all the nutritious foods offered both in the dining courts and in our On-the-GO! locations on campus" (dining.purdue.edu). However, students that do not, or cannot, partake in these services may experience great difficulties in accessing affordable, nutrient-dense foods. Graduate students, in particular, make up a population that often do not enroll in campus cafeteria meal plans. These students rely on other modes, such as supermarkets, to purchase the food they consume. Prior to January of 2018, only one supermarket, Fresh City Market, existed on campus or was within walking distance of campus. Fresh City Market closed its doors on January 19th, 2018 (Suter, 2018) and no supermarkets have since opened up on or within walking distance of Purdue University's campus. Progress is being made as a small-format Target retail store was opened in the summer of 2020 near campus on the corner of State Street and Northwestern Avenue. While this store is not a supermarket, the store does contain a small kiosk containing fresh fruits and vegetables.

Graduate students are a unique population that find themselves sandwiched between their undergraduate counterparts and professional colleagues. The challenges and responsibilities of simultaneously performing duties as a college student and professional-in-training can weigh heavily on this population. In fact, a 2018 Harvard University study found that graduate students experience moderate or severe symptoms of depression and anxiety at a rate more than three times the population average (Barreira, 2018). Challenges graduate students face include financial decision-making, time constraints, marital/parental responsibilities and healthy lifestyle sacrifices. According to Sallie May (2017), graduate students pay for around 77 percent of their education with money they have earned, saved, or borrowed, while undergrads pay only 30 percent of their education from the same type of resources. In addition, only 15 percent of graduate students' costs are covered by free financial aid, which includes grants, fellowships, scholarships, or tuition waivers. These account for less than half of the 35 percent that free financial aid pays for undergraduate costs. This is important because financial constraints on individuals and families can lead to a poorer quality diet (Johns Hopkins University Bloomberg School of Public Health, 2007). At Purdue University, many financial benefits are available to graduate students such as grants, fellowships and assistantships. According to Glassdoor.com, the typical Purdue University graduate student receives a salary of $24,891, but this could still leave graduate students and their families food insecure. To receive SNAP benefits, gross monthly income must be at or below 130 percent of the poverty line, which for an individual with no dependents is $16,588. This amount is well below what the average graduate student receives, and thus, they are not eligible to receive SNAP benefits. Rental costs in greater Lafayette are rising rapidly. In, West Lafayette average monthly rent values increased 2% to $1,203 from July 2019 to July 2020 (Rent Cafe, 2020). Just across the river in Lafayette, where many graduate students also live, average monthly rent costs increased 5% to $812 in the past 12 months (Rent Cafe, 2020). In addition, the average cost of utilities for an apartment renter in the United States is $100-$150 (Move.org, 2020). Additional fees to use University facilities (~$348 per semester) are not included in tuition waiver packages. Books (variable) and parking permits ($100 annually for the lowest access parking permit) are also to be paid for by the average graduate student. In addition, graduate students are susceptible to negative monetary effects from changing University policies For example, Dave Bangert of the Lafayette Journal & Courier documented that Purdue University payroll changes during the summer of 2019 left many graduate students with paychecks cut by "as much as half." The article is titled, "Purdue payroll changes leave grad students strapped, angry this summer." "Transition pay" bonuses were paid to students as a way to ameliorate negative effects caused by paycheck cuts. However, these transition payments were simply portions of graduate student summer salaries that had to be paid back.

While government organizations such as the HFFI cite distance to a supermarket as the biggest factor affecting fruit and vegetable consumption, many studies find the issue to be much more complex. Economics appears to play a major role in the consumption of fruits and vegetables, which could leave many graduate students at a major disadvantage when purchasing healthy foods. One review of 27 studies throughout 10 countries revealed that healthier diets are more expensive, with the healthiest diets rich in fruits, vegetables, nuts and fish being $1.50 more expensive per day than the least expensive diets rich in processed foods, meats and refined grains (Rao et al., 2013). The cost of healthy foods appears to have an equal, if not greater, effect on food consumption patterns than simply supermarket distance from their place of residence (Drewnowski, 2012).

The USDA mainly measures food insecurity rates using purely financial measures, but there exist many more factors that affect it (Peterson and Freidus, 2020). Many graduate students, especially Master's degree seeking students, take courses while also conducting research projects with the intention of publishing a thesis and/or scientific articles to journals in their respective fields. Oftentimes, they also work as Research Assistants (RA) or Teaching Assistants (TA) to help mitigate the costs of graduate school. Graduate students are older than undergraduate students, on average, which can greatly increase the amount of responsibilities they devote their time towards. The average age of a graduate student, according to the National Center for Education Statistics (NCES), is 32.28 years. The NCES estimates that around 38% of United States graduate students are married and 23% have children. Research, teaching, learning and personal responsibilities make for a very busy schedule. Individuals faced with greater time constraints from work, childcare, or commuting often turn to unhealthy convenience foods (Rahkovsky, 2018). Purdue University's campus and surrounding areas' food desert status, minimal disposable incomes and schedule constraints place Purdue's graduate student population at a high risk for adherence to unhealthy diets, such as the Standard American Diet.

Aside from low access, pay and free time, transportation is another challenge facing students at Purdue University that may contribute to food insecurity and healthy food choices. According to walkscore.com, West Lafayette, Indiana has a "Walk Score" of 49, which categorizes the city as a "car dependent city". Many graduate students also reside in neighboring Lafayette, Indiana, which has a Walk Score of only 36. This means that most errands require a car in both cities, which creates challenges for those that do not have access to personal vehicles. This is particularly problematic among the large international student population at Purdue University. As of Fall 2019, Purdue enrolled 4,434 international graduate students, and many of these students do not have access to a personal vehicle. Purdue University seeks to mitigate these negative consequences by utilizing the services of CityBus as its form of public transportation. Purdue students are granted free and unlimited access to any local CityBus route with a valid Purdue photo ID. CityBus contains "Campus Loops" and bus routes throughout the Lafayette and West Lafayette area. Public transportation offers challenges in and of itself, but the recent COVID-19 pandemic has created even more issues for those that rely on public transportation to get to wherever they purchase groceries. On Monday, March 23rd, CityBus suspended "most campus loops and apartment shuttles services", wrote Jordan Burrows of local station WLFI (Burrows, 2019). As of the writing of this literature review in August 2020, Purdue has issued COVID-19-specific transportation guidelines, including a 50% reduced occupancy restriction and a 6 feet maintenance of separation while utilizing Purdue University owned transportation. Seven bus loops (Lark & Alight, 23, 35, 14, 15, 17 and 28) have been suspended since Friday, May 8th until classes resume during the first week of the Fall 2020 semester. These routes run through residential hotspots and 4 of them (14, 15, 17 and 28) are considered "Campus Loops." These closures and restrictions add another challenge to accessing grocery stores that students, especially students without cars, face. Moreover, graduate students often continue to work on campus during the summer months. Citybus commonly reduces bus routes in the summer but this was even more challenging during the COVID pandemic when additional closures were put into place. Thus, international graduate students could be at greater risk for experiencing challenges disproportionately when purchasing groceries.

Barriers to accessing nutrient-dense fruits and vegetables are important to uncover and ameliorate for many reasons. One of the most important reasons is that diets during graduate school can have lifelong effects on the health of students, since eating patterns are often created and solidified during adolescence and young adulthood (Bull, 1992). Bandura's SCT also posits that past experiences and current habits are important to recognize because they influence an individual's "reinforcements, expectations and expectancies, all of which shape whether a person will engage in a specific behavior and the reasons why a person engages in a behavior" (Bandura, 1989). Early adulthood is a key stage of life as working habits begin to form that will carry on throughout the work-life of individuals. Poor habits in early adulthood can easily transform into years of consuming a poor diet consistently exceeding the daily recommendations for sodium, saturated fats and added sugar, thus increasing the risk of weight gain and onset of obesity. Obesity increases the risk for a whole host of diseases and conditions, such as cardiovascular disease, diabetes, certain cancers, liver and kidney disease and sleep apnea, among others (Pi-Sunyer, 2009).

Poor diets can also negatively impact graduate students in the short-term. Diets high in sodium, fats and sugar, but low in nutrient-dense fruits and vegetables has been found to reduce self-control (Gailliot and Baumeister, 2018), harm mental health (Selhub, 2020) and reduce the chance of academic success (Reuter et al., 2020). On the flip side, diets rich in fruits and vegetables increase the chance of reaping benefits both in the short- and long-term. A healthy diet can boost energy levels throughout the day (Breymeyer et al., 2016), increase productivity (Wurtman et al.,

2003) and decrease the risk of incidence for many non-communicable chronic diseases (Hung et al., 2004).

The consequences of a poor diet are commonly known, just as the consequences of healthy dietary behaviors are known, but do college students know of these benefits? And if so, do college students take this knowledge into account when choosing what to eat? Understanding this is important in the context of this study to get a general insight into how effective a healthy food landscape would be at promoting healthy dietary behaviors on the individual level among college-aged students. Karine Côté-Boucher of the University of Montreal administered a questionnaire to 385 junior college students in the Quebec City area to answer these questions. The survey was designed to identify the determinants in the intention of young adults in postsecondary education institutions to eat at least five servings of fruits and vegetables per day for the following three months. They discovered that students with strong intentions to adhere to the recommended diet had a better understanding of the benefits of consuming the daily recommended amount of fruits and vegetables. These benefits included: fruits and vegetables help maintain good health, and fruits and vegetables are foods that bring pleasure by tasting good. In addition, these students had a better understanding of factors that assisted or inhibited their desire to consume more daily fruits and vegetables (Côté-Boucher, 2012). The results of this study give public health experts a better understanding of characteristics that lead young adults to positively change dietary patterns. These results also show congruence with the Theory of Planned Behavior (TPB) that states "intentions to perform behaviors of different kinds can be predicted with high accuracy from attitudes toward the behavior, subjective norms, and perceived behavioral control" (Ajzen, 1991). McDermott et al. (2015) concluded in a systematic literature search of 22 reports that "TPB (Theory of Planned Behavior) variables have medium to large associations with both intention and dietary patterns and may therefore provide program designers with a guide for designing effective interventions".

Graduate students that do decide to include more fruits and vegetables in their diets may find themselves asking themselves the question: are there significant nutritional differences between fresh, frozen and canned produce? The question beneath that question for strapped-for-cash graduate students may be: which form of produce offers the most nutrients for its price? The short answer is that nutrient losses vary depending on which nutrient is being observed. For example, fresh produce begins to lose vitamin C immediately after harvest and during transit. Fresh produce also tends to lose more vitamin C during the cooking process than canned produce does

(Rickman et al., 2007). However, temperature during storage, the length of blanching time, crop variety and grower processes can also directly influence vitamin C content" (Breene, 2007; Lee CY, 1976). Canned fruits and vegetables also tend to have slightly lower levels of B vitamins than fresh produce (Miller and Knudson, 2013). Levels of vitamin A, carotenoids, vitamin E, minerals and fiber are generally similar in fresh, frozen and canned produce (Miller and Knudson, 2013; Rickman et al., 2007). Speaking economically, one study concluded that canned foods had the lowest total cost per edible portion, and a lower or comparable cost-per-nutrient compared with fresh or frozen foods (Connell, 2012). However, purchasing healthy canned vegetables has its own unique set of challenges. Registered dietitian Esther Ellis, a member of the Academy of Nutrition and Dietetics, recommends watching out for canned fruits and vegetables that are packed in syrup (added sugars) and sodium. She advises that if canned food is the only option, choose fruits that are packed in "water, 100 percent juice or in its own juices." She also advises selecting canned vegetables labeled "no salt added" or "low sodium" (Ellis, 2020).

While fresh fruits and vegetables are generally considered more nutritious, consumers may be surprised to find out that fresh produce at the supermarket may not be as fresh or nutritious as they thought. Some fresh produce is picked before it is fully ripe and thus does not contain the maximum amount of vitamins and minerals it could have had it ripened before being harvested. Other products, like apples and pears, can be stored up to 12 months before appearing on supermarket shelves (Brown, 2017). For this and various other reasons, one famous study from the University of Texas by Davis et al. (2009) observed statistically reliable declines for protein, calcium, phosphorous, iron, riboflavin and ascorbic acid in 43 different crops from the mid-20th century to 2004 (Davis et al., 2009). Dr. Michelle Hauser, a clinical fellow in medicine at Harvard Medical School and a certified chef and nutrition educator says, "if freshly picked produce is easy for you to come by, then it may be slightly higher in nutrients than its frozen counterparts." Fully mature, local produce consumed quickly after harvest appears to be the most sure-fire option for obtaining both high nutrient quantity and taste. Fully mature, local produce may be difficult to acquire for graduate students, especially those living in food deserts. Fortunately, chances are that individuals who consume a healthy diet with a variety of fruits and vegetables in any form are getting the essential nutrients the human body needs for good health (Harvard Medical School Publishing, 2014).

While canned and frozen produce do appear to provide the required amount of nutrients for good health, consumer demand for fresh, locally grown produce is on the rise, especially for younger populations (Low et al., 2015). Food deserts, by definition, lack the appropriate supermarket presence that may provide locally grown produce for purchase. One way to help fix the lack of availability of fresh produce in food desert regions has been to implement farmer's markets within their borders (Franck et al., 2020). Fortunately for Purdue University students, the city of Lafayette, Indiana farmer's market operates on Saturdays from 8:00-12:30 PM from May to October. Purdue University also hosts a farmer's market on its campus Thursdays 11:00-2:00 PM from May to July and Thursday 11:00-3:00 PM from August-October. Lastly, the city of West Lafayette offers a farmer's market Wednesdays 3:30-7:00 PM from May-October. However, while these markets can lead to greater consumption of fresh fruits and vegetables in communities (Gary-Webb, 2018; Bowling et al., 2016), they cannot be relied upon to alleviate all fresh produce disparities in a community (Lowery et al., 2016), specifically during the winter months.

Alternatively, private and public funds can invest in community gardens to help provide fresh, nutritious food. Community gardens have proven effective at improving the food landscape in neighborhoods such as Kensington of inner Phildelphia, where one local child told community garden workers that, "It's easier to get a gun in our neighborhood than it is to get a salad." (Claieborne, 2012). Claieborne's "The Simple Way" network of community gardens has helped sprout life through the pavement that is Kensington's once completely barren food landscape. Community gardens are also a promising alternative for graduate students to increase their fruit and vegetable consumption (Barnidge et al., 2013), while also gaining crucial exposure working in fruit and vegetable production. Gaining knowledge of how food is grown increases the chances of implementing positive nutritional behaviors (Chung et al., 2019; Kulik et al., 2019; Inghram, 2019). Grow Local is a network of community gardens in the greater Lafayette, Indiana area that provides ten "sharing gardens" which are open to the public. Produce grown on these gardens is available to anyone to take what they need, regardless of whether they have the time to participate in the growing process. Grow Local provides a unique opportunity for Purdue University graduate students to gain hands-on food production experience, while enhancing access to fresh fruits and vegetables. However, garden managers have reported that they have had trouble connecting with Purdue students, despite the fact that they know large volumes of students are living near the gardens.

The goal of this study was to determine if food insecurity and poor eating choices are indeed a problem among Purdue University's graduate population, and if so, among which segments are they most problematic. We also sought to identify key factors that might be contributing to these challenges, and identify potential barriers preventing students from learning about or participating in Lafayette's GrowLocal community garden network.

2.2 Materials and Methods

2.2.1 Survey

To our knowledge, no previous research projects have been conducted focusing solely on graduate students' access to fruits and vegetables. Undoubtedly, no such study exists that focuses solely on the Purdue University graduate student population. Our team discovered this knowledge gap and conducted an initial investigation of this important topic. The purpose of this survey was not to quantify the abundance, breadth and depth of healthy food access that Purdue graduate students may face. Instead, the purpose was to investigate the *existence* of potential barriers Purdue University graduate students may face when consuming and purchasing healthy foods. These barriers could be individual or structural. Individual refers to barriers like taste preference and nutrition education that people face when deciding which foods to purchase and consume. Structural barriers refer to logistical elements of the food landscape that affect whether purchasing and consuming nutritious foods is possible, such as access or transportation. Also included is a section inquiring about the effects of the current COVID-19 global pandemic on food purchasing, preparation, and consumption attitudes and behaviors while at Purdue University. The survey ended with a series of questions asking Purdue graduate students about local community gardens as an addendum of sorts to previous data as community gardens are a known alternative solution for those wishing to increase fruit and vegetable access in food deserts. We wished to collect data in this section to: 1) understand the extent to which Purdue graduate students are cognizant of local community gardens, 2) raise awareness of the existence of local community garden services and volunteer opportunities at these gardens, and 3) discover which mediums would be optimal for community gardens to post opportunities when trying to reach Purdue University graduate students. We included these questions because community gardens are a potential option for increasing fruit and vegetable access to those living in food deserts, and have the potential to positively impact fruit and vegetable consumption (Barnidge et al., 2013). Our results will be shared with Grow Local organizational leaders in neighboring Lafayette, Indiana to help them improve communication with Purdue students.

The method of gathering this information was done utilizing survey methodology. Survey data is a crucially important method for gathering scientific data. The United States constitution requires that a decennial total population sampling survey, or census, be taken to produce statistics on the US population. These results help the government understand the changing demographics of the nation and make sure that each district has the correct amount of representation in the House of Representatives. Survey results from major polling corporations are especially visible during election years, such as during the current 2020 presidential election. If political polling has taught the scientific world anything, it is that nothing can substitute for the real behaviors of individuals. This is one reason why the results of this study are not being used to generalize for the larger graduate student population. Polling a subset of a population can lead to predictions that prove to be different than when played out in the real world. This conjures up the famous image of President Harry S. Truman holding a copy of the Chicago Tribune newspaper on Election Day 1948. Quota sampling results during the 1948 election led many news outlets to believe the Republican candidate, Thomas E. Dewey of New York, would easily defeat Democratic incumbent, Harry S. Truman. The Chicago Tribune famously ran a premature headline reading “Dewey defeats Truman” that Harry Truman triumphantly held up after his victory. Acquiring accurate, generalizable information from samples of a population by mode of survey research is attainable, but much care must be taken during the methodology and design phase. Health organizations rely on survey data to gain critical needs assessments. The National Health and Nutrition Examination Survey (NHANES) done by the Centers for Disease Control and Prevention (CDC) is an excellent example of how survey work can help professionals understand the health and nutritional status of adults and children in the United States. Other examples include the National Health Interview Survey, the Medical Expenditure Panel Survey and the National Ambulatory Medical Care Survey. (Sakshaug and West, 2014)

Our survey was created and administered online. There are many advantages of a self-administered online survey. One is that every respondent receives the same questions in the same manner. Researchers need not worry about interview bias or response effects due to features or characteristics of the interviewer (Bernard, 2011). Another advantage is that questions can be more complex, as very intricate and detailed questions are oftentimes harder for respondents to follow in face-to-face or telephone interviews (Bernard, 2011). Anonymity also provides an advantage for this mode of survey. Research done by L. Peterson et al. (1996) provided evidence that respondents are more willing to respond truthfully to sensitive information such as premarital sex experiences and arrest records when completing computer-based surveys compared to pencil and paper-based surveys (Peterson et al., 1996). Grimm (2010) provided evidence that administering a Qualtrics-based survey online provides a decreased risk of responses being affected by social desirability bias, which is the "tendency of research subjects to give socially desirable responses instead of choosing responses that are reflective of their true feelings". Social desirability bias is especially important to reconcile for questions asking about fruit and vegetable consumption intentions, attitudes and consumption patterns (Herbert, 1995; Hebert et al., 2008). The vast majority of respondents have a general understanding from common wisdom and years of education that consuming fruits and vegetables are a part of a healthy and socially desirable diet. Finally, one unexpected advantage to an online-based survey is that they can be administered in a socially-distant fashion.

We had originally intended to use a stratified random sampling for our survey. This would have involved attending many random seminars across campus and asking permission to use ~10 minutes prior to the start of the seminar to ask students to fill out the survey via phone or laptop. In this way, we would help ensure that graduate students from most, if not all, departments would fill out the survey and have their voices heard. Unfortunately, our team was required to adapt as the World Health Organization declared COVID-19 a global pandemic on Wednesday, March 11th, 2020. Many organizations, companies and governments enacted mandates to reduce exposure time to others while in public. Many colleges and universities, including Purdue University, closed their doors and sent students home during the spring 2020 semester. Consequently, rather than utilizing stratified random sampling, we chose to use a form of purposive sampling known as "total population sampling." Total population sampling has the advantage of reducing the risk of "missing possible insight from members that are not included" (dissertation.laerd.org). For example, significant biasing could occur were we to only sample students working in the fields of study associated with health, nutrition and food systems. There is a chance that these students care more about the topic of fruit and vegetable access and consumption compared to the average Purdue University graduate student. However, every human needs to eat to sustain life and every graduate student has their own unique experiences with accessing fruits and vegetables while attending Purdue University. Therefore, a total sampling method was chosen. Statistical generalizations cannot be made about the target population when using purposive sampling methods, but analytical generalizations may be made (Laerd Dissertation, n.d.). This is in accordance with the goals and aims of this survey. We chose to contact the Purdue Graduate School office and inquire about the possibility of sending a mass email to every Master's and PhD student on their enrollment list. The Graduate School agreed once all Institutional Review Board (IRB) requirements had been accounted for. IRB requirements were satisfied and all graduate students were reached via email sent from the Graduate School to every Purdue University graduate student on the morning of Wednesday, May 20th, 2020.

Respondents were allowed to maintain a level of anonymity while completing the survey. Our survey did not ask for names or home addresses of respondents. The survey did, however, ask for certain demographic information. This included: Sex, Master's or PhD student, citizenship status, graduate program, work/school responsibilities (teach and/or take classes and/or conduct research), primary mode of transportation, financial status and general location of primary living space in relation to Purdue University's campus (On campus, off campus within a 5 minute drive or off campus with a 5+ minute drive). Ascertaining generalized financial status was accomplished with the help of anthropologist Andrew Flachs of Purdue University. Question 7 was written to accomplish this task: "Which option best describes who pays your cell phone bill? (Check all that apply)". The choices were: Myself, parents, other family member, spouse, friend and I do not own a cell phone. Revealing financial information is often a sensitive ask for individuals, but creative measures can be taken to gain truthful responses (Duncan, 2001).

Understanding who took the survey and how they might represent a specific subset of the graduate student population is important to distinguish before conducting further demographic tests. For example, it is necessary to know if survey respondents represented a subset more interested in nutrition and food security as this would provide more evidence that diets lacking in fruits and vegetables are more likely to be from lack of access due to a poor food landscape rather than lack of desire or interest. In fact, this is what we discovered by examining the 5% of graduate students that took our survey. This group of Purdue graduate students represented a subset likely more interested in nutrition than the average graduate student as indicated by their willingness to take a survey on the topic of access to nutritious foods. 24 hour dietary recall data also provides evidence of this through the observation that they consumed fruits and vegetables at rates much higher than national averages. Not only was this subset more engaged with nutrition than the average graduate student, this subset was also more enthusiastic and passionate about pushing for positive change when it comes to nutrition and food security compared to their fellow graduate students. Because this subset was an enthusiastic, engaged subset, their responses should be understood within that context. Responses coming from this subset are likely biased toward seeing the negative aspects of the food landscape more than the average graduate student who may not care or may not be affected by the lack of access to nutritious foods. In this way, they are a better gauge of the food landscape in terms of nutritious food access compared to, say, a student who continually eats poorly at SAD food establishments and has no desire to change or seek out places that sell fresh fruits and vegetables. Nonetheless, the graduate students who did not take the survey would have provided useful data and because we missed them we missed the data they could have provided. Less enthusiastic, less engaged graduate students could provide a clearer picture of where the average lies in terms of fruit and vegetable consumption patterns, what drives them to purchase fruit and vegetable when they do and what the overall level of demand is for increasing access to establishments that sell fruits and vegetables. Understanding the motivations and barriers that these graduate students face provides rich insight that public health professionals and city legislators could use to implement effective strategies that target specific barriers that stand in the way of less enthusiastic populations.

Once we gained a better understanding of the subset that took our survey, we ran statistical analyses comparing responses of subgroups within the Purdue University graduate student population. These statistical comparisons can shed light on disparities of food access and consumption patterns between certain demographic groups within the aforementioned subset of the Purdue graduate student population.

First and foremost, we sought to discover difficulties that Purdue graduate students faced when purchasing and consuming nutritious foods. Analysis of survey data paired with demographic data was used to understand differentiations in difficulties on the individual level and the structural level. Perhaps individual-driven variables, such as the cost of a healthy diet or time commitment it takes to prepare a healthy diet are reasons why individuals may choose not to engage in healthy dietary behaviors. Structurally, poor transportation and lack of access to nutritious foods could be to blame for many students' poor dietary habits. In this way, responses given by graduate students will give us a firsthand account of whether perceived barriers to a healthy diet are primarily from individual choice or from structural defects in the local food landscape.

Another question we wanted to investigate was how many servings of fruits and vegetables are Purdue graduate students roughly consuming daily? The 24 hour recall is a commonly utilized method to collect information from respondents of the types and quantities of foods consumed in the past 24 hours. Our decisions to use this as our method of collecting fruit and vegetable consumption data was largely based on the fact that 24 hour recalls are commonly used in larger population studies (Tucker, K.L., 2007). Our target population of around 10,000 people is not large when compared to national-level consumption surveys. However, we are employing a total population sampling method and 24 hour recalls "provide detail on foods consumed at the population level" (Tucker, K.L., 2007). This method does have its drawbacks as many studies find that individuals, especially women and people with increased body weights, often underreport and underestimate portion sizes and servings (Tucker, K.L., 2007; Young and Nestle, 2008; Kye et al., 2014). Another limitation of this recall method is that it only represents one day in the life of the graduate student. Food consumption patterns change on a day-to-day basis. The COVID-19 pandemic caused reductions in supermarket hours, cancellations to public transportation routes and has created an unusual epoch that likely skewed the food consumption patterns we found. One potential advantage gained from conducting this research during these extraordinary circumstances is that our data has the potential to be used as a comparison were another researcher to collect data on the same population during non-pandemic periods of time. The purpose of employing the 24 hour recalls was not to split hairs about specific numerical values on the consumption of fruits and vegetables by Purdue University graduate students. Instead, the purpose of the 24 hour recalls was to gain a general idea of consumption patterns among those that chose to participate.

The next piece of information desired was: where are Purdue graduate students purchasing their fresh produce? Understanding where Purdue University graduate students purchase fresh produce is important because it gives our team a general idea of the most popular grocery stores in the area. We chose to ask about fresh produce specifically because consumer preferences for fresh fruits and vegetables continue to rise, especially during the current COVID-19 global pandemic (Blue Book Services, 2020). Fresh produce can also be obtained from locally grown sources like farmer's markets and community gardens, so these results will give us an initial understanding of the utilization of these services to obtain fruits and vegetables. This also gives us insight into potential increasing demand among this population for locally grown produce. Responses to these questions, in conjunction with responses to proceeding questions, have the potential to give insight into the role that fresh produce plays in the diets of Purdue University graduate students.

Questions 15, 16 and 17 were designed to help answer two very important research questions. The principles of the TPB elucidate the importance of understanding an individual's motivations when attempting to understand "considerable variance in actual behavior" (Azjen, 1991). The principles of the SCT describes the reciprocal deterministic relationship individuals experience with other people, their environment and their behavior. With these two theories in mind, we created questions 15, 16 and 17 to better understand what motivates students to purchase, or not purchase, nutritious foods, and what are the perceived barriers to including fresh produce in the diets of these students?

The COVID-19 global pandemic prompted our research team to include questions dedicated to understanding the effects of food access that graduate students had experienced, and were experiencing now as a result of the pandemic. It is vitally important to understand the context within which the respondents took the survey. The World Health Organization declared COVID-19 a global pandemic on Wednesday, March 11th, 2020. CityBus, the local bus system suspended "most campus loops and apartment shuttles services" on Monday, March 23rd, 2020. CityBus began running operations again in limited capacity beginning in April 2020 (Burrows, 2020). The survey was open from Wednesday, May 20th, 2020 to Tuesday, June 30th, 2020. This section was designed to provide information for the following research questions:

- How has the COVID-19 pandemic affected overall food purchasing and preparation habits?

- Has the COVID-19 pandemic made any of the following factors more or less important when obtaining groceries?
    - Taste, Freshness, Price, Nutrition, Convenience/Easily Prepared, Food Safety
- Has the COVID-19 pandemic catalyzed permanent change to future grocery purchasing methods?
- How has the COVID-19 pandemic affected overall fruit and vegetable consumption patterns?
- How has the COVID-19 pandemic affected volunteering needs and safety?

The final section of the survey sought to gain knowledge on the following questions regarding Purdue University graduate students and community gardens:

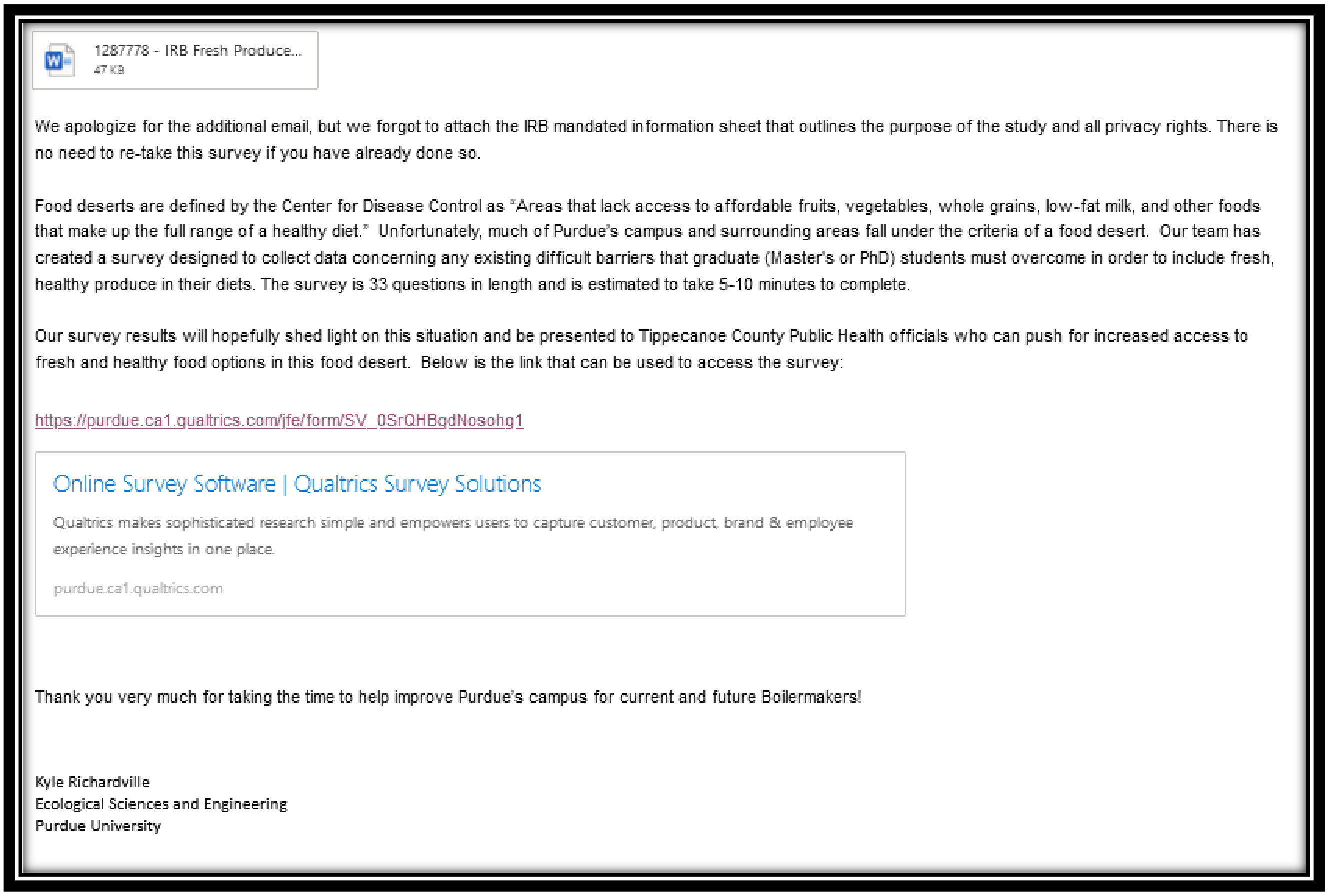
- What are Purdue University graduate students' general knowledge and attitudes regarding community gardens in the area?
- Do Purdue University graduate students volunteer at local community gardens? How often?
- What motivates Purdue graduate students to volunteer at local community gardens?
- Do Purdue graduate students have any interest in ever volunteering at a local community garden?
- What medium should community gardens use to best transmit volunteer opportunities to Purdue University graduate students?

. The 33-question survey we conducted included 16 single answer multiple-choice questions, 4 multiple answer multiple-choice questions, 7 Likert matrix table questions and 6 open-ended text entry questions. Qualitative and quantitative data was collected from the survey, but all questions were analyzed quantitatively. However, there are advantages to obtaining data qualitatively, even though it is more difficult to quantify compared to quantitative data. Qualitative research provides a "rich, contextualized understanding of some aspect of human experience through the intensive study of particular cases" (Polit, 2010). We sought information in the words of graduate students themselves on the subjects of fresh produce consumption motivations, perceived barriers to nutritious foods and the effects of the COVID-19 pandemic on food purchasing and consumption patterns.

This research project underwent a pretest once a complete draft of the survey was finished. Pretests are a necessary step in the process of developing a valid and reliable social science research survey because they allow respondents to provide feedback on various facets of the survey (Converse and Presser 1986). Feedback includes: relevant, comprehensive and mutually exclusive response options and clearly articulated questions. Pretesting allows the researcher to address any issues that obstruct the respondent from interpreting the survey in the same manner as the researcher (Converse and Presser 1986). Fellow members of Lori Hoagland's Agroecology Lab, who were also graduate students at the time of pretesting, volunteered to perform pretesting duties. This sample of respondents was chosen because they were members of the target population for the survey and could provide tailored feedback for the final draft. Geographical convenience was also factored into the decision to choose these respondents as face-to-face feedback was possible once respondents had completed the survey.

Feedback gathered from pretesting was evaluated and questions were edited to address troubled areas where reorganization and rephrasing were needed. The final draft of the survey was completed once this editing was complete. IRB approval for the final draft and its protocol was granted in early May. The full survey can be found in appendix A. Through coordination with Purdue University's Graduate School, the survey was sent via email. Unfortunately, the IRB's required information sheet was not attached to the primary email sent to the target population. The information sheet is required to be attached to the survey invitation as a way to inform respondents about what the respondent's responsibilities are should they choose to participate, what the potential benefits and risks are if they participate, what rights they have and contact information should they have any questions. The IRB information sheet is essential and acts as an alternative method for informed consent because receiving a signature from every respondent is not feasible in this case, especially during pandemic circumstances. Consequently, a subsequent email was sent with the appropriate IRB-mandated information sheet. Figure 2.5 is a screenshot of the second email sent on the afternoon of Wednesday, May 20th, 2020 to every member of the Purdue University graduate student population.

.



1287778 - IRB Fresh Produce...
47 KB

We apologize for the additional email, but we forgot to attach the IRB mandated information sheet that outlines the purpose of the study and all privacy rights. There is no need to re-take this survey if you have already done so.

Food deserts are defined by the Center for Disease Control as "Areas that lack access to affordable fruits, vegetables, whole grains, low-fat milk, and other foods that make up the full range of a healthy diet." Unfortunately, much of Purdue's campus and surrounding areas fall under the criteria of a food desert. Our team has created a survey designed to collect data concerning any existing difficult barriers that graduate (Master's or PhD) students must overcome in order to include fresh, healthy produce in their diets. The survey is 33 questions in length and is estimated to take 5-10 minutes to complete.

Our survey results will hopefully shed light on this situation and be presented to Tippecanoe County Public Health officials who can push for increased access to fresh and healthy food options in this food desert. Below is the link that can be used to access the survey:

https://purdue.ca1.qualtrics.com/jfe/form/SV_0SrQHBgdNosohg1

Online Survey Software | Qualtrics Survey Solutions

Qualtrics makes sophisticated research simple and empowers users to capture customer, product, brand & employee experience insights in one place.

purdue.ca1.qualtrics.com

Thank you very much for taking the time to help improve Purdue's campus for current and future Boilermakers!

Kyle Richardville
Ecological Sciences and Engineering
Purdue University

Figure 195. Screenshot of the second email sent to all Purdue University graduate students, which includes an explanation of the IRB information sheet's absence from the first email

2.2.2 Survey Respondents

All Purdue University-West Lafayette Main Campus graduate students were eligible to complete the survey. Enrollment for the spring 2020 semester was 9,529 students and the demographics of this population breaks down into the following major categories:

Table 192. Purdue University graduate student demographics for gender, degree type and domestic or international status based on spring 2020 data

<u>Sex</u>	
Men	**Women**
5,576 (58.5%)	3,953 (41.5%)
<u>Type of Degree</u>	
Doctoral Students	**Master's Students**
4,690 (49.2%)	4,382 (46.0%)
<u>Domestic & International</u>	
Domestic	**International**
5,343 (56.1%)	4,186 (43.9%)

2.2.3 Qualtrics® survey instrument

By choice and necessity due to the COVID-19 pandemic, our team decided to solely rely on an online survey for this research project. The survey, entitled "Purdue Graduate Students' Fresh Produce Consumption in the Food Desert", was developed and conducted at Purdue University-West Lafayette Main Campus using the services of Qualtrics®. Qualtrics® is a web-based survey creation, collection, and analysis software tool. Its software can be used for the creation of open surveys, targeted (panel) surveys, and open polling. Purdue University has a Qualtrics® license allowing faculty and staff direct access to Qualtrics® for university-related activities.

Inductive coding was used to analyze data from open-ended questions. This form of coding is also called open coding. Inductive coding starts from scratch and creates codes based on the qualitative data itself. No set codebook exists prior to analysis; all codes arise directly from the survey responses (Medelyan, 2020). Within inductive coding, flat coding was used a frame that assigns the same level of specificity and importance to each code. While this might feel like an easier and faster method for manual coding, it can be difficult to organize and navigate the themes and concepts as you create more and more codes. Figuring out which themes are most important can be more difficult, which can slow down decision making (Medelyan, 2020). Macqueen (1998) stated "With brief responses to open-ended questions on standardized surveys there is generally little need to develop structural codes because the data is pre-structured by question and participant. Here the goal is to code the text in such a way that the information can be combined meaningfully with a quantitative database. The codes are used primarily to signal the presence or absence of particular pieces of information". Analyzing Likert data was also crucial to gain useful data. Likert modeling as ordinal can sometimes lead to more accurate parameter estimates, but as the number of responses increases (up to 6 he argues), continuous modeling will also work (Green, 2020).

2.2.4 Statistical Analyses

Data collection for multiple choice, Likert-style questions and open-ended responses were quantified using Qualtrics®-made reports and the coding software R. R is a language and environment for statistical computing and graphics. Open-ended responses from questions 16, 17 and 18 were categorized and quantified by the primary researcher, Kyle Richardville. Question 16 ("I include fresh produce in my diet because") coded response variables were grouped in such a way that we could investigate the main reasons why survey participants consumed fresh produce. Examples include: because it is healthy or because it is tasty. Question 17 ("Is fresh produce difficult to include in your diet? (If yes, please explain why. If no, please write "No.")) coded response variables were grouped in such a way that we could investigate whether the majority of perceived barriers were internally or externally driven. Question 18 ("How has the recent coronavirus epidemic affected food purchasing and preparation habits?") coded response variables were grouped in such a way that we could investigate how the COVID-19 pandemic affected individual choice, as well as how it affected the structure of the food landscape. These give us a good insight into the resiliency of the local food landscape to stressful conditions. Responses to these questions were categorized, coded and entered into a Microsoft Excel spreadsheet as dichotomous (binary) responses where a response containing the variable received a "1" and responses that did not contain the variable were given a "0". Mr. Richardville's quantifications of the results were compared against another researchers' categorizations of open-ended results to ensure intercoder reliability. Intercoder reliability tests were done to ensure that interpretation of the open-ended responses by Mr. Richardville was statistically objective and valid. The equation used to ensure reliability was taken from the Sage encyclopedia of communication research methods (Allen, 2017). The equation is:

- Intercoder reliability = 2 * M / (N_1 + N_2)
  - "M" – Total number of decisions that the two coders agree on
  - "N_1" Number of decisions made by Coder 1
  - "N_2" – Number of decisions made by Coder 2

Upon reviewing intercoder reliability tests, objectivity and validity of open-ended response categorizations was achieved when intercoder reliability scores of 0.7 or above were reached (Allen, 2017). All of the open-ended results presented in the proceeding sections received scores of 0.7 or above.

Once intercoder reliability test results supported the validity of open-ended response interpretations, R was utilized for statistical analyses of all data. The data was analyzed by the Kruskal-Wallis test. The Kruskal-Wallis test, or one-way ANOVA on ranks, is a common non-parametric method for testing whether samples originate from the same distribution. (Kruskal & Wallis, 1952). This test is used to compare two or more independent samples of equal or different sample sizes and it indicates whether at least one sample is stochastically dominant over the other. The Kruskal-Wallis test is utilized for non-normally distributed data. Normality was tested using the Shapiro-Wilk test. It was determined that data for our survey were non-normal after being analyzed by the Shapiro-Wilk test. Thus, the Kruskal-Wallis test was utilized to compare results for the following groups:

- Male vs Female students
- PhD vs Master's degree seeking students
- American vs International students
- Citizen of a developing nation vs Citizen of a non-developing nation (*Developing nations categorized by the UN's "country classifications")
- Work/School Responsibilities (Check all that apply)
  - Research/Lab work
  - Classes
  - Teaching
- Primary transportation status
  - Personal Vehicle
  - Public Transportation

    - Reliant on friends and family
    - Ride-sharing companies such as Uber or Lyft
    - Walking, biking, skateboard or scooter
- Financial status (Based on who pays their cell phone bill)
- Primary place of residence
    - On campus
    - Off campus within a 5 minute drive of campus
    - Off campus within a 5+ minute drive of campus

2.3 Results

2.3.1 Demographics

A total of 480 (5.0%) out of 9,529 eligible Purdue University graduate students responded to the survey (Table 2.3).

Table 193. Demographics of survey respondents

	Demographic	Frequency	Percentage	Actual
Sex	Female	247	51.5%	41.5%
	Male	221	46.0%	58.5%
	Prefer Not to Answer	12	2.5%	N/A
Degree	PhD	347	72.3%	49.2%
	Master's	133	27.7%	46.0%
College	Engineering	171	35.6%	36.3%
	Science	103	21.5%	13.7%
	Agriculture	62	12.9%	6.4%
	Liberal Arts	36	7.5%	10.4%
	Health & Human Sciences	32	6.7%	6.5%
	Education	23	4.8%	8.4%
	Management	22	4.6%	6.6%
	Polytechnic	11	2.3%	7.8%
	Pharmacy	9	1.9%	1.4%
	Veterinary	9	1.9%	1.1%
	Interdisciplinary	2	0.4%	0.6%
Citizenship	USA	284	59.2%	56.1%
	International	196	40.8%	43.9%
Developing Nation Citizenship	No	356	74.2%	N/A
	Yes	124	25.8%	N/A
Residence	Off campus with a 5+ minute drive to campus	275	57.4%	N/A
	Off campus within a 5 minute drive of campus	148	30.9%	N/A
	On campus	56	11.7%	N/A
Work Responsibilities	Research/Lab work only	179	37.4%	N/A
	Research/Lab work + Classes	110	23.0%	N/A
	Classes only	60	12.5%	N/A
	Research/Lab work + Classes + Teaching	60	12.5%	N/A
	Research/Lab work + Teaching	40	8.4%	N/A
	Classes + Teaching	23	4.8%	N/A
	Teaching only	7	1.5%	N/A

Table 2.3 continued

Transportation	I drive my own personal vehicle while at Purdue	294	61.3%	N/A
	I rely on public transportation to get to places	99	20.6%	N/A
	I mainly get around by walking, bike, skateboard, or scooter	66	13.8%	N/A
	I rely on friends and family to drive me around to places	19	4.0%	N/A
	I rely on ride-sharing companies like Uber to get to places	2	0.4%	N/A
Financial Status (Who pays cell phone bill?)	Myself	307	64.1%	N/A
	Parents	114	23.8%	N/A
	Myself + Parents	21	4.4%	N/A
	Myself + Spouse	13	2.7%	N/A
	Spouse	10	2.1%	N/A
	Other Family Members	7	1.5%	N/A
	Myself + Other Family Members	3	0.6%	N/A
	I do not own a cell phone	1	0.2%	N/A
	Parents + Other Family Members	1	0.2%	N/A
	Parents + Spouse	1	0.2%	N/A
	Myself + Parents + Spouse	1	0.2%	N/A
	Friend	0	0.0%	N/A
	Myself + Friend	0	0.0%	N/A

There appear to be two categories where responses were noticeably different from the between the demographics of graduate students at Purdue University. Females comprised over half of the respondents for our survey even though 58.5% of the actual graduate student population are male. In addition, PhD student survey respondents outnumbered Master’s student respondents by almost 3:1 even though 49.2% of the actual Purdue University graduate student population are classified by the university as seeking Doctoral seeking.

2.3.2 Overall Respondent Results

Fruit and Vegetable Consumption

Survey respondents were asked to provide 24-hour recall information for both fruits and vegetables of any kind (fresh, frozen or canned). The mean number of reported servings of fruits was 6.9 servings/day^{-1} and the mean number of reported servings of vegetables was 7.6 servings/day^{-1}. The World Health Organization (WHO) recommends that individuals consume at least 5 servings/day^{-1} for fruits and 5 servings/day^{-1} for vegetables. Only 29 (7%) respondents reported consuming less than 5 servings/day^{-1} of fruits and 30 (7%) reported the same for vegetables.

Major fresh produce consumption location

421 Purdue graduate student participants responded to this question. Of the 421, 416 (98.8%) reported the supermarket as their primary fresh produce consumption location. Convenient stores (.5%), food pantries (0.2%), personal garden/local farmer (0.2%), and restaurants (0.2%) also received responses.

Major Location for Produce Used for Cooking and Eating at Home

422 Purdue graduate student participants responded to this question. Of the 422, 146 (34.6%) said Payless, followed by 115 (27.2%) for Walmart, 51 (12.1%) for Meijer, 44 (10.4%) for Aldi, 36 (8.5%) for Fresh Thyme, 6 (1.4%) for Purdue's ACE Food Pantry, and 3 (0.7%) for local farmer's markets. 13 other locations and/or online delivery services, such as Imperfect Foods, received 4 or fewer votes.

Important factors when purchasing fresh produce: <u>Taste</u>

419 Purdue graduate student participants responded to this Likert-style question. Of the 419, 250 (59.7%) reported taste as a "Very Important" factor, 130 (31.0%) reported taste as "Slightly Important", 26 (6.2%) "Neither Important nor Unimportant", 9 (2.1%) "Slightly Unimportant", and 4 (0.9%) "Very unimportant".

Important factors when purchasing fresh produce: <u>Freshness</u>

418 Purdue graduate student participants responded to this Likert-style question. Of the 418, 290 (69.4%) reported freshness as a “Very Important” factor, 114 (27.3%) reported taste as “Slightly Important”, 10 (2.4%) “Neither Important nor Unimportant”, 3 (0.7%) “Slightly Unimportant”, and 1 (0.2%) “Very unimportant”.

Important factors when purchasing fresh produce: <u>Low Price</u>

417 Purdue graduate student participants responded to this Likert-style question. Of the 417, 190 (45.6%) reported low price as a “Slightly Important” factor, 149 (35.7%) reported taste as “Very Important”, 46 (11.0%) “Neither Important nor Unimportant”, 26 (6.2%) “Slightly Unimportant”, and 6 (1.4%) “Very unimportant”.

Important factors when purchasing fresh produce: <u>High Price Ensuring Premium Quality</u>

418 Purdue graduate student participants responded to this Likert-style question. Of the 418, 115 (27.5%) reported high price ensuring premium quality as “Neither Important nor Unimportant” factor, 107 (25.6%) reported taste as “Very Unimportant”. 102 (24.4%) “Slightly Important”, 51 (12.2%) “Slightly Important”, and 43 (10.3%) “Very Important”.

Important factors when purchasing fresh produce: <u>Nutrition</u>

416 Purdue graduate student participants responded to this Likert-style question. Of the 416, 183 (44.0%) reported nutrition as “Slightly Important” factor, 165 (39.7%) reported nutrition as “Very Important”, 47 (11.3%) “Neither Important nor Unimportant”, 18 (4.3%) “Slightly Unimportant”, and 3 (0.7%) “Very Unimportant”.

Important factors when purchasing fresh produce: <u>Convenience/Easily prepared</u>

419 Purdue graduate student participants responded to this Likert-style question. Of the 419, 164 (39.1%) reported convenience/easy preparation as a “Slightly Important” factor, 117 (27.9%) reported taste as “Very Important”. 82 (19.6%) “Neither Important nor Unimportant”, 35 (8.4%) “Slightly Unimportant”, and 21 (5.0%) “Very Unimportant”.

Important factors when purchasing fresh produce: Food Safety

419 Purdue graduate student participants responded to this Likert-style question. Of the 419, 189 (45.1%) reported food safety as “Very Important” factor, 116 (27.7%) reported taste as “Slightly Important”, 79 (18.9%) “Neither Important nor Unimportant”, 23 (5.5%) “Slightly Unimportant”, and 12 (2.9%) “Very Unimportant”.

I include fresh produce in my diet because:

This open-ended question asked respondents to list reasons why they include fresh produce in their diets. 285 (75.0%) of responses listed the health benefits of fresh produce as a reason. 119 (31.3%) responses detailed the tastiness of fresh produce, 35 (9.2%) said it makes them feel better and/or energized, 17 (4.5%) appreciate its utilization when cooking, 13 (3.4%) mentioned their vegan or vegetarian lifestyle, 13 (3.4%) specifically prefer fresh produce to canned/frozen produce, 11 (2.9%) cited consuming fresh produce as a lifelong habit formed during childhood due to familial or cultural influences, and 9 (2.4%) say fresh produce is cheap. Other answers received 6 or fewer responses.

Is fresh produce difficult to include in your diet?

This open ended-question asked respondents whether there were difficult barriers to overcome when including fresh produce in their diets. Out of 396 responses, 241 (60.8%) of students responded with some variation of “no, including fresh produce in my diet is not difficult.” 39 (9.8%) students said that fresh produce’s short shelf life makes these products difficult to include in their diets. 38 (9.6%) students feel that there are low levels of access to healthy options on or near Purdue University’s campus. 37 (9.3%) students mentioned that the cost of fresh produce as prohibitive and 37(9.3%) responses contained rhetoric that the extra time and effort that fresh produce requires as a difficulty. 17 (4.3%) students cited transportation as a reason that fresh produce is difficult to include in their diet and 17 (4.3%) students cited the current COVID-19 as a barrier to overcome. 11 (2.8%) students do not like the taste and/or prefer other foods to fresh produce and 9 (2.3%) said that they do not have the proper knowledge to cook and make dishes with fresh produce. Medical conditions, living on the road, not being filling enough and little kitchen space to hold them all received two or fewer responses.

How has the recent coronavirus epidemic affected food purchasing and preparation habits?

This open-ended question asked respondents to describe ways in which the recent COVID-19 pandemic has affected food purchasing and preparation habits. Out of 607 listed effects, "Less trips to the store" was mentioned 125 times (20.6%), followed by "Harder to access fresh produce" (69 times, 11.4%), "Not much" (66 times, 10.9%), "Eat at home more" (50 times, 8.2%) and "Run out of fresh produce/Fresh produce spoils before return trip to the store due to less frequent trips" (40 times, 6.6%).

How has the coronavirus pandemic affected the importance of taste when obtaining groceries?

406 Purdue graduate student participants responded to this Likert-style question asking about the influence that the recent coronavirus global pandemic has had on the importance of taste when purchasing fresh produce. Of the 406, 292 (71.9%) reported "Just the Same", 82 (20.2%) reported taste as "Less Important". 20 (4.9%) "More Important", 12 (3.0%) "Isn't and never has been an Important Factor".

How has the coronavirus pandemic affected the importance of <u>freshness</u> when obtaining groceries?

407 Purdue graduate student participants responded to this Likert-style question. Of the 407, 264 (64.9%) reported "Just the Same", 76 (18.7%) reported freshness as "Less Important". 61 (15.0%) "More Important", 6 (1.5%) "Isn't and never has been an Important Factor".

How has the coronavirus pandemic affected the importance of <u>price</u> when obtaining groceries?

406 Purdue graduate student participants responded to this Likert-style question. Of the 406, 203 (50.0%) reported "Just the Same", 109 (26.8%) reported freshness as "More Important". 85 (20.9%) "Less Important", 9 (2.2%) "Isn't and never has been an Important Factor".

How has the coronavirus pandemic affected the importance of nutrition when obtaining groceries?

406 Purdue graduate student participants responded to this Likert-style question. Of the 406, 290 (71.4%) reported "Just the Same", 81 (20.0%) reported nutrition as "More Important". 24 (5.9%) "Less Important", 11 (2.7%) "Isn't and never has been an Important Factor".

How has the coronavirus pandemic affected the importance ***of convenience/easily prepared when obtaining groceries?***

406 Purdue graduate student participants responded to this Likert-style question. Of the 406, 222 (54.7 %) reported "Just the Same", 83 (20.4%) reported convenience as "Less Important". 69 (17.0%) "More Important", 32 (7.9%) "Isn't and never has been an Important Factor".

How has the coronavirus pandemic affected the importance of food safety when obtaining groceries?

403 Purdue graduate student participants responded to this Likert-style question. Of the 403, 205 (50.9%) reported "Just the Same", 169 (41.9%) reported convenience as "More Important". 23 (5.7%) "Less Important", 6 (1.5%) "Isn't and never has been an Important Factor".

Once the situation returns to normal, how likely are you to have your groceries delivered to your place of residence?

395 Purdue graduate student participants responded to this multiple choice question. Of the 395, 260 (65.8%) say they didn't before the pandemic and won't once it is lifted, 76 (19.2%) report they will utilize this service just as much, 44 (11.1%) will utilize this service more than before the coronavirus pandemic, 15 (3.8%) say they will get their groceries delivered to them less than they did before the pandemic.

Once the situation returns to normal, how likely are you to order your groceries online and physically pick them up at the supermarket?

408 Purdue graduate student participants responded to this multiple-choice question. Of the 408, 254 (62.3%) say they didn't before the pandemic and won't once it is lifted, 95 (23.3%) report they will utilize this service just as much, 44 (10.8%) will utilize this service more than

before the coronavirus pandemic, 15 (3.7%) say they will get their groceries delivered to them less than they did before the pandemic.

How would you describe the level of difficulty associated with food purchasing during the coronavirus pandemic?

408 Purdue graduate student participants responded to this multiple-choice question. Of the 408, 279 (68.4%) say it has been "Harder than normal", 118 (28.9%) report it is the same as during normal times, 11 (2.7%) say it has been "Easier than normal".

How would you describe your current overall fruit and vegetable consumption compared to pre-coronavirus pandemic times?

408 Purdue graduate student participants responded to this multiple-choice question. Of the 408, 221 (54.2%) say they are eating the same amount as before, 130 (31.9%) report eating less than normal, 57 (14.0%) say they are eating more than before.

How do you believe the coronavirus pandemic has affected volunteering needs?

407 Purdue graduate student participants responded to this multiple choice question. Of the 407, 294 (72.2%) say volunteering needs are higher than normal, 78 (19.2%) report needs being the same as before, 35 (8.6%) say volunteering needs are less than before.

How much risk are you putting yourself in when volunteering in a hospital during the coronavirus pandemic?

407 Purdue graduate student participants responded to this multiple-choice question. Of the 407, 248 (60.9%) say volunteering in a hospital is an "extreme level of risk", 73 (17.9%) report a slightly above average risk, 46 (11.3%) say there are no risks at all, 25 (6.1%) say that there is an average level of risk, and 4 (1.0%) say there is very little risk.

How much risk are you putting yourself in when volunteering for a <u>blood drive</u> during the coronavirus pandemic?

395 Purdue graduate student participants responded to this multiple-choice question. Of the 395, 138 (34.9%) say volunteering at a blood drive puts them at a slightly above average risk, 106 (26.8%) report an extreme level of risk, 73 (18.5%) say there is an average level of risk, 49 (12.4%) say that there is no risk at all, and 29 (7.3%) say there is very little risk.

How much risk are you putting yourself in when volunteering in a <u>retirement home or assisted living center</u> during the coronavirus pandemic?

394 Purdue graduate student participants responded to this multiple-choice question. Of the 394, 145 (36.8%) say volunteering at a retirement home or assisted living center carries an extreme level of risk, 120 (30.5%) report an above average level of risk, 57 (14.5%) say there is an average level of risk, 46 (11.7%) say that there is no risk at all, and 26 (6.6%) say there is very little risk.

How much risk are you putting yourself in when volunteering at <u>food distribution centers</u> during the coronavirus pandemic?

394 Purdue graduate student participants responded to this multiple-choice question. Of the 394, 146 (37.1%) say volunteering at a food distribution center carries a slightly above average level of risk, 105 (26.6%) report an average level of risk, 50 (12.7%) say there is very little risk, 49 (12.4%) say that there is no risk, and 44 (11.2%) say there is an extreme level of risk.

How much risk are you putting yourself in when volunteering at a <u>community garden</u> during the coronavirus pandemic?

394 Purdue graduate student participants responded to this multiple-choice question. Of the 394, 120 (30.5%) say volunteering at a community garden carries very little risk, 106 (26.9%) report an average level of risk, 82 (20.8%) say there is a slightly above average risk, 71 (18.0%) say that there is no risk at all, and 15 (3.8%) say there is an extreme level of risk.

Are there any community gardens within a 15 minute drive of your place of residence?

397 Purdue graduate student participants responded to this multiple-choice question. Of the 397, 230 (57.9%) said they were unsure, 109 (27.5%) report that there is one, 58 (14.6%) say there is not.

How often do you volunteer at a community garden?

397 Purdue graduate student participants responded to this multiple-choice question. Of the 397, 379 (95.5%) said they do not volunteer at community gardens, 10 (2.5%) report they volunteer once a year, 4 (1.0%) say they volunteer there once every 6 months, 3 (0.8%) say they volunteer there monthly and 1 (0.3%) said they volunteer there weekly.

Does a community garden bring value to the communities where they are located by helping to put food on the table?

383 Purdue graduate student participants responded to this multiple-choice question. Of the 383, 170 (44.4%) said they somewhat agree that it brings this value to the community, 92 (24.0%) strongly agree, 85 (22.2%) say they neither agree nor disagree, 27 (7.0%) somewhat disagree and 9 (2.3%) said they strongly disagree.

Does a community garden bring value to the communities where they are located by increasing the community's sense of togetherness?

382 Purdue graduate student participants responded to this multiple-choice question. Of the 382, 168 (44.0%) said they somewhat agree that it brings this value to the community, 111 (29.1%) strongly agree, 82 (21.5%) say they neither agree nor disagree, 13 (3.4%) somewhat disagree and 8 (2.1%) said they strongly disagree.

Does a community garden bring value to the communities where they are located by improving the environment?

383 Purdue graduate student participants responded to this multiple-choice question. Of the 383, 166 (43.3%) said they somewhat agree that it brings this value to the community, 119 (31.1%) strongly agree, 83 (21.7%) say they neither agree nor disagree, 10 (2.6%) somewhat disagree and 5 (1.3%) said they strongly disagree.

Does a community garden bring value to the communities where they are located because they are <u>essential in a functioning community?</u>

383 Purdue graduate student participants responded to this multiple-choice question. Of the 383, 155 (40.5%) said they neither agree nor disagree, 97 (25.3%) somewhat agree, 55 (14.4%) strongly agree, 52 (13.6%) somewhat disagree and 24 (6.3%) said they strongly disagree.

I would be more likely to volunteer at a local community garden if there was <u>better communication of opportunities to me.</u>

381 Purdue graduate student participants responded to this multiple-choice question. Of the 381, 157 (41.2%) said they somewhat agree, 140 (36.7%) strongly agree, 57 (15.0%) neither agree nor disagree, 14 (3.7%) strongly disagree and 13 (3.4%) said they somewhat disagree.

I would be more likely to volunteer at a local community garden if <u>transportation was provided to and from.</u>

382 Purdue graduate student participants responded to this multiple-choice question. Of the 382, 151 (39.5%) said they neither agree nor disagree, 64 (16.8%) strongly disagree, 63 (16.5%) somewhat disagree, 55 (14.4%) strongly agree and 49 (12.8%) said they somewhat agree.

I would be more likely to volunteer at a local community garden if <u>I knew the community garden staff were friendly and accommodating</u>.

380 Purdue graduate student participants responded to this multiple-choice question. Of the 380, 173 (45.5%) said they somewhat agree, 97 (25.5%) strongly agree, 86 (22.6%) neither agree nor disagree, 13 (3.4%) somewhat disagree and 11 (2.9%) said they strongly disagree.

I would be more likely to volunteer at a local community garden if <u>I knew my level of gardening experience was accepted.</u>

382 Purdue graduate student participants responded to this multiple-choice question. Of the 382, 152 (39.8%) said they somewhat agree, 103 (27.0%) neither agree nor disagree, 92 (24.1%) strongly agree, 22 (5.8%) somewhat disagree and 13 (3.4%) said they strongly disagree.

I would be more likely to volunteer at a local community garden if <u>I had the proper clothing.</u>

379 Purdue graduate student participants responded to this multiple-choice question. Of the 379, 175 (46.2%) said they neither agree nor disagree, 90 (23.7%) said they somewhat agree, 44 (11.6%) somewhat disagree, 37 (9.8%) strongly agree and 33 (8.7%) said they strongly disagree.

I would be more likely to volunteer at a local community garden if <u>opportunities did not conflict with my schedule.</u>

382 Purdue graduate student participants responded to this multiple-choice question. Of the 382, 165 (43.2%) said they strongly agree, 120 (31.4%) said they somewhat agree, 76 (19.9%) neither agree nor disagree, 12 (3.1%) somewhat disagree and 9 (2.4%) said they strongly disagree.

I would be more likely to volunteer at a local community garden if <u>I was able to take home fresh produce from the garden.</u>

381 Purdue graduate student participants responded to this multiple-choice question. Of the 381, 144 (37.8%) said they strongly agree, 117 (30.7%) said they somewhat agree, 86 (22.6%) neither agree nor disagree, 19 (5.0%) strongly disagree and 15 (3.9%) said they somewhat disagree.

Are you interested in volunteering at a community garden?

385 Purdue graduate student participants responded to this multiple-choice question. Of the 385, 230 (59.7%) said yes, 155 (40.3%) said no.

What is the best method for a community garden to convey information about the work they do and volunteering opportunities?

374 Purdue graduate student participants responded to this multiple choice question. Of the 374, 220 (58.8%) said email, 119 (31.8%) said social media pages, 18 (4.8%) said text, 17 (4.5%) said another mode.

2.3.3 Group Comparisons

The following tables visualize the existence of significant differences between responses of the various comparison groups. Significant differences were assigned for p-values less than 0.05. Significant differences between groups with more than two options (transportation, residence, work duties and financial status) were allotted footnotes below the table to distinguish which of the groups differed from each other. A written description of major significant differences for each group is provided in the subsequent section.

Table 194. Kruskal-Wallis group results for total fruit consumption, total vegetable consumption and location where majority of fresh produce is consumed

	Total Fruit Consumption	Total Vegetable Consumption	Location where majority of fresh produce is consumed
M vs F	None	None	None
PhD vs Master's	None	None	None
USA vs Int	None	None	None
Developing nations	None	None	None
Transportation	Sig Dif [1]	None	None
Residence	None	None	None
Work Duties	None	None	None
Financial Status	None	None	None

[1] Students who rely on public transportation consumed significantly less fruits than students who mainly get around by walking, bike, skateboard, or scooter.

Table 195. Kruskal-Wallis group results comparing perceived consumer importance of taste, freshness, low price, high price ensuring high quality, nutrition, convenience and food safety when purchasing fresh produce

	Importance of **Taste** when purchasing fresh produce	Importance of **Freshness** when purchasing fresh produce	Importance of **Low Price** when purchasing fresh produce	Importance of **High Price Ensuring High Quality** when purchasing fresh produce	Importance of **Nutrition** when purchasing fresh produce	Importance of **Convenience/Easily Prepared** when purchasing fresh produce	Importance of **Food Safety** when purchasing fresh produce
Sex	Sig Dif	Sig Dif	None	None	Sig Dif	None	None
PhD vs Master's	None	None	Sig Dif	None	None	None	None
USA vs Int	Sig Dif	None	None	Sig Dif	None	None	None
Developing nations	Sig Dif	None	None	Sig Dif	None	None	None
Transportation	Sig Dif [1]	None	None	None	None	None	None
Residence	None	None	None	None	None	None	None
Work Duties	None	None	Sig Dif [2]	None	None	Sig Dif [3]	None
Financial Status	None	None	None	None	None	None	None

[1] Students who drive their own personal vehicles listed taste as more important than students who mainly get around by walking, bike, skateboard, or scooter and student who use ride-sharing services like Uber.

[2] Students who only have research/lab work and students who have research/lab work, classes and teach list low price as more important than student who only take classes.

[3] Students who have research/lab work, classes and teach list convenience/easily preparedness as more important when purchasing fresh produce than students who only teach and students who have research/lab work and teach.

Table 196. Kruskal-Wallis group results comparing the effects that the COVID-19 pandemic has had on perceived consumer importance of taste, freshness, price, nutrition, convenience and food safety when purchasing fresh produce.

	Effects of COVID-19 on **Taste** as a factor for purchasing fresh produce	Effects of COVID-19 on **Freshness** as a factor for purchasing fresh produce	Effects of COVID-19 on **Price** as a factor for purchasing fresh produce	Effects of COVID-19 on **Nutrition** as a factor for purchasing fresh produce	Effects of COVID-19 on **Convenience/Easily Prepared** as a factor for purchasing fresh produce	Effects of COVID-19 on **Food Safety** as a factor for purchasing fresh produce
M vs F	Sig Dif	Sig Dif	None	None	None	None
PhD vs Master's	None	None	None	None	None	None
USA vs Int	Sig Dif	None	None	None	None	None
Developing nations	None	None	None	None	None	None
Transportation	None	None	None	None	None	None
Residence	None	None	None	None	None	None
Work Duties	None	None	None	None	None	None
Financial Status	None	None	None	None	None	None

Table 197. Kruskal-Wallis group results comparing how the COVID-19 pandemic has affected the usage of grocery delivery services, grocery curbside pickup services, the level of difficulty purchasing food and overall fruit and vegetable consumption

	Effects of COVID-19 on the usage of **grocery delivery services**	Effects of COVID-19 on the usage of **grocery curbside pickup services**	Level of difficulty for purchasing food during COVID-19	Effects of COVID-19 on overall fruit and vegetable consumption
M vs F	Sig Dif	None	None	Sig Dif
PhD vs M	None	None	None	None
USA vs Int	Sig Dif	Sig Dif	None	None
Developing nations	Sig Dif	None	None	None
Transportation	None	None	None	None
Residence	None	None	None	None
Work Duties	None	None	None	None
Financial Status	None	None	None	None

Table 198. Kruskal-Wallis group results comparing how the COVID-19 pandemic has affected overall volunteering needs and the level of risk for volunteering at (1) hospitals, (2) blood drives, (3) assisted living centers, (4) food distribution centers and (5) community gardens**.**

	Effects of COVID-19 on **overall volunteering needs**	Level of risk while volunteering at a **hospital** during COVID-19	Level of risk while volunteering at a **blood drive** during COVID-19	Level of risk while volunteering at a **assisted living/retirement home** during COVID-19	Level of risk while volunteering at a **food distribution center** during COVID-19	Level of risk while volunteering at a **community garden** during COVID-19
M vs F	None	Sig Dif	Sig Dif	Sig Dif	Sig Dif	Sig Dif
PhD vs M	None	None	None	None	None	None
USA vs Int	Sig Dif	None	None	Sig Dif	None	None
Developing nations	None	None	None	None	None	None
Transportation	None	None	None	None	None	None
Residence	None	None	None	None	None	Sig Dif [1]
Work Duties	None	None	None	None	None	None
Financial Status	None	None	None	None	None	None

[1] Students who live more than a five minute drive off of campus list the level of risk for volunteering at a community garden as higher than students who live on campus.

Table 199. Kruskal-Wallis group results comparing the awareness of local community gardens, frequency of community garden volunteering and perceived level of value that community gardens bring to their community by (1) putting food on the table, (2) increasing its sense of togetherness, (3) improving the environment they are embedded in and (4) being a necessary element of a functioning community.

	Are there any community gardens within 15 minutes of your place of residence?	Frequency of community garden volunteering	Community gardens bring value to a community by **putting food on the table**	Community gardens bring value to a community by **increasing its sense of togetherness**	Community gardens bring value to a community by **improving the environment they are embedded in**	Community gardens bring value to a community by **being a necessary element of a functioning community**
M vs F	Sig Dif	Sig Dif	Sig Dif	Sig Dif	Sig Dif	Sig Dif
PhD vs M	None	None	None	None	None	None
USA vs Int	None	None	Sig Dif	None	Sig Dif	None
Developing nations	None	None	None	None	None	None
Transportation	None	None	None	Sig Dif [3]	None	None
Residence	None	None	None	None	None	None
Work Duties	Sig Dif [1]	None	Sig Dif [2]	Sig Dif [4]	None	Sig Dif [5]
Financial Status	None	None	None	None	None	None

[1] Students who have research/lab work and teach acknowledged that a community garden exists within 15 of their place of residence more often than students who have classes and teach and students who only teach.

[2] Students who have research/lab work, classes and teach and students that have research/lab work and classes list community garden's value of putting food on the table as higher than students who only have classes and students who only teach.

[3] Students whose main form of transportation is family and friends listed a community garden's value of togetherness as higher than students whose main form of transportation is a personal vehicle.

[4] Students who have research/lab work, classes and teach and students who have research/lab work and classes listed a community garden's value of togetherness as higher than students who only teach and students who have classes and teach.

[5] Students who have research/lab work, classes and teach listed a community garden as a necessary element in a functioning society as higher than students who only take classes, students who only teach and student who have classes and teach.

Table 1910. Kruskal-Wallis group results comparing likelihood to volunteer at a community garden if (1) opportunities were better communicated, (2) transportation was provided, (3) they knew the staff was friendly and accommodating, (4) they knew my level of skill was accepted, (5) they had the proper clothing, (6) opportunities didn't conflict with their schedule and (7) they were able to take home fresh produce from the community garden.

	More likely to volunteer at a community garden if **opportunities were better communicated**	More likely to volunteer at a community garden if **transportation was provided**	More likely to volunteer at a community garden if **I knew the staff was friendly and accommodating**	More likely to volunteer at a community garden if **I knew my level of skill was accepted**	More likely to volunteer at a community garden if **I had the proper clothing**	More likely to volunteer at a community garden if **opportunities didn't conflict with my schedule**	More likely to volunteer at a community garden if **I was able to take home fresh produce from the community garden**
M vs F	Sig Dif	None	Sig Dif	Sig Dif	None	None	None
PhD vs M	None	None	None	None	None	None	None
USA vs Int	Sig Dif	Sig Dif	None	None	None	None	Sig Dif
Developing nations	None	Sig Dif	None	None	None	None	Sig Dif
Transportation	None	Sig Dif [2]	None	Sig Dif [3]	Sig Dif [4]	None	None
Residence	None	None	None	None	None	None	None
Work Duties	Sig Dif [1]	None	None	None	None	Sig Dif [5]	Sig Dif [6]
Financial Status	None	None	None	None	None	None	None

[1] Students who have research/lab work and classes reported being more likely to volunteer if opportunities are better communicated than students who only have classes and students who only teach.

[2] Students whose main form of transportation is family and friends reported being more likely to volunteer if transportation was provided than students whose main form of transportation is a personal vehicle, students whose main form of transportation is public transportation and students who mainly get around by walking, bike, skateboard or scooter. Students whose main form of transportation is public transportation and students who get around by walking, bike, skateboard or scooter reported being more likely to volunteer at community gardens if transportation was provided than students whose main form of transportation is a personal vehicle.

[3] Students whose main form of transportation is family and friends reported being more likely to volunteer at a community garden if they knew their level of skill was accepted than students whose main form of transportation is a personal vehicle and students who mainly get around by walking, bike, skateboard or scooter.

[4] Students whose main form of transportation is family and friends reported being more likely to volunteer at a community garden if they had the appropriate clothing than students whose main form of transportation is a personal vehicle and students who mainly get around by walking, bike, skateboard or scooter.

[5] Students who have research/lab work, classes and teach reported being more likely to volunteer at a community garden if opportunities did not conflict with their schedules than students who only have classes, students who only teach and students who have classes and teach.

[6] Students who have research/lab work, classes and teach reported being more likely to volunteer at a community garden if they were able to take home fresh produce from the community garden than students who only have research/lab work, student who only have classes, students who only teach and students who take classes and teach

Table 1911. Kruskal-Wallis group results comparing interest in volunteering at a community garden and the best method for a community garden to convey volunteer opportunities.

	Are you interested in volunteering at a community garden?
M vs F	None
PhD vs M	None
USA vs Int	Sig Dif
Developing nations	None
Transportation	Sig Dif [1]
Residence	None
Work Duties	None
Financial Status	None

[1]Students whose main form of transportation is a personal vehicle reported being more interested in volunteering at a community garden than students whose main form of transportation is public transportation.

2.3.4 Notable Group Comparison Trends

Transportation comparison trends

Students that get around mainly by walking, biking, skateboard or scooter consume significantly more fruits (7.81 serving day^{-1}) than those students who drive their own personal vehicle (6.79 servings/day^{-1}) and ones who mainly use public transportation (6.65 servings day^{-1}).

Developing nation comparison trends

Those from developing nations report taste as a significantly less important factor when purchasing fresh produce. However, they see high price ensuring premium quality as a significantly more important factor. Those from non-developing nations are significantly more likely to decrease their utilization of grocery delivery services to their place of residence when the COVID-19 pandemic is over.

American and International student comparison trends

International students report taste as a significantly less important factor when purchasing fresh produce compared to American students. However, they see high price ensuring premium quality as a significantly more important factor. American students are significantly more likely to decrease their use of grocery delivery services and grocery store pick-ups compared to international students when the COVID-19 pandemic is over. American students reported community gardens have value putting food on the table and improving the environment they are located in at significantly higher levels than international students. American students are also more likely to volunteer at community gardens if opportunities are better communicated to them and they were able to take free food from the community garden. International students are more likely to volunteer if transportation is provided. When asked if interested in volunteering at a community garden at some point in the future, international students indicated more interested than American students.

PhD and Master's student comparison trends

PhD students report low price as a significantly more important factor when purchasing fresh produce compared to Master's students. This was the only category in which a significant difference was found.

Male vs Female student comparison trends

Female students report taste, freshness and nutrition as significantly more important factors when purchasing fresh produce compared to male students. Female students also report taste and freshness as more important factors due to the COVID-19 pandemic at levels significantly higher than male students. Female students are less likely to get their groceries delivered to their place of residence after the COVID-19 pandemic ends compared to male students. Male students reported eating less fruits and vegetables due to the COVID-19 pandemic compared to female students. Female students report volunteering in hospitals, blood drives, retirement homes/assisted living facilities, food distribution centers and community gardens as riskier during the COVID-19 pandemic compared to male students. Male students report volunteering at community gardens more than female students. Female students reported that community gardens have value putting food on the table, bringing togetherness, improving the environment and being a necessary faction of a functioning community in which they are located at significantly higher levels than males students. Females are more likely to volunteer at community gardens if opportunities are better communicated to them, they knew the staff was friendly and accommodating and they knew the staff was accepting of their gardening skill levels.

Comparisons between groups: Open-ended questions

ANOVA results for question 16 ("I include fresh produce in my diet because:") indicate that the Purdue University graduate students who took the survey include fresh produce in their diet for many of the same reasons, no matter the demographic being compared. The only demographic to show a significant ($p < 0.05$) relationship was found between those from developing nations and vegetarianism or veganism. 7.5% of graduate students from developing nations cited vegetarianism or veganism as a reason for including fresh produce in their diets, as compared to 2.0% of graduate students from non-developing nations. While a significant relationship was not found statistically, it is still interesting to note that 11 (7.5%) international respondents listed including fresh produce in their diet as a lifetime habit, while 0 American respondents listed this as a reason.

Question 17 ("Is fresh produce difficult to include in your diet?") results were analyzed and only one category of response variable resulted in a significant relationship between demographic and response. This category was transportation. Significantly more international students cited transportation as a difficulty for including fresh produce in their diet as compared to American students. Similarly, students from developing nations cited transportation significantly more often as a barrier to access as compared to students from non-developing nations.

Question 18 ("How has the recent coronavirus pandemic affected food purchasing and preparation habits?") results showed a significant relationship between one's work responsibilities and the likelihood of their diet becoming "unhealthier" due to the coronavirus pandemic. Respondents that have multiple work responsibilities mentioned their diets becoming unhealthier at higher percentages than those who only had one current responsibility (Table 2.12).

Table 1912. Frequency of responses for question 18 ("How has the recent coronavirus pandemic affected food purchasing and preparation habits?") that listed unhealthier dietary behaviors grouped by work responsibilities.

Responsibility	Responses	Total	Percentage
Classes + Teaching	2	22	9.1%
Research/Lab work + Classes + Teaching	4	50	8.0%
Research/Lab work + Teaching	2	32	6.2%
Research/Lab work + Classes	3	93	3.2%
Research/Lab work	4	147	2.7%
Classes	0	47	0.0%
Teaching	0	5	0.0%

2.4 Discussion

2.4.1 Individual and Structural Difficulties When Purchasing and Consumption Produce

Understood in light of the TPB, fresh produce purchasing and consumption motivations at least partially drive respondents to actually purchase and consume fresh, healthy foods in their diets. Survey respondents listed taste and food safety as their top priorities when obtaining groceries. These results are somewhat unexpected as price is consistently one of the largest factors commonly cited as a major food choice determinant (Institute of Medicine and National Research Council of the National Academies, 2013). The COVID-19 pandemic most likely played a large part in the variance observed as it caused change in the mindset of people when thinking about what food to purchase, where to purchase food and how to purchase food.

Purdue University closed its doors for the spring semester in March and the local community as a whole was under nearly universal shut down at the time the survey was open to respondents for completion. Thus, the COVID-19 pandemic personally affected every survey respondent in one way or another and was most likely affecting fresh produce purchasing and consumption motivations. In fact, 42% of respondents noted that food safety was a "More Important" factor to them when obtaining groceries compared to pre-COVID-19 times. Price appears to have taken a back seat to food safety for many graduate students. While individual motivations and risk assessments appear to have shifted, this was not the only factor that drove behavior changes when purchasing and consuming produce during the height of COVID-19 confusion and panic. Many survey respondents discussed a lack of access to nutritious foods solely based on the fact that the local area does not have sufficient establishments that sell nutritious foods. In other words, the perceived food landscape in the area is of poor quality to many of survey respondents so they must overcome structural barriers when purchasing and consuming a healthy diet. The COVID-19 pandemic appears to have wounded an already weak food landscape structure. West Lafayette and Lafayette supermarkets and public transportation systems experienced shutdowns and legislative restrictions during this time, which appears to have disproportionately affected certain individuals in the community, thus exacerbating barriers to accessing produce individuals already faced. Graduate students without personal vehicles were especially negatively affected by these restrictions.

Unsurprisingly, the COVID-19 pandemic has not affected the importance of nutrition when obtaining groceries for many survey respondents. The vast majority of survey respondents listed the importance of nutrition as "Just the same" as it was before the pandemic. This is disappointing and illustrates a potential reason why nutrition is not discussed more during the current public health crisis for its effect on short- and long-term health and wellness. Healthy lifestyle habits, including proper nutrition, do not receive the attention that they so rightly deserve from media sources that most Americans get their information from. In fact, one COVID -19 review by Chaari et al. (2020) states that deficiency of vitamins, mineral and polyphenols has profound consequences on "susceptibility to infection" and obesity largely caused by physical inactivity and excess consumption of carbohydrates and saturated fats "can deregulate the immune system of the host thereby increasing susceptibility to infection." Another COVID-19 review by Razdan et al. (2020) states that "maintaining adequate vitamin D levels is vital to prevent getting infected or to ward off the infection without mortality, in case it occurs." Lastly, a September 2020 trial administering high doses of Calcifediol, a main metabolite of vitamin D, found that it "significantly reduced the need for ICU treatment of patients requiring hospitalization due to proven COVID-19." (Entrenas et al., 2020). Unfortunately, consumers of the news frequently hear about vaccine and drug development, but very little about nutrition's role in disease prevention and recovery. These discussions of pharmacological importance are sandwiched between commercial breaks inundated with advertisements displaying the miraculous effects of prescription drugs of all sorts that cure ailments of all shapes and sizes. The average American sees nine drug advertisement a day, which corresponds to more time a year than the time they spend with their primary care physician (Ventola, 2011). It may be slightly concerning to learn that the United States is one of only two nations worldwide that legally allow direct-to-consumer prescription medication advertising. The other is the small island nation of New Zealand. A shift in the paradigm of nutrition's role in maintaining health and preventing disease for the American culture is desperately needed, especially during a pandemic.

The subset of the Purdue graduate student population that took our survey was discovered to be more enthusiastic and engaged with nutrition than the average graduate student so learning that this population said nutrition was not more important of a factor when purchasing and consuming produce is concerning. If this subset does not see proper nutrition as more important, then there is a large chance that the rest of the population also does not see nutrition as more important. Access to nutritious foods is one of the first necessary steps in the process of changing behaviors and attitudes concerning healthy diets. If there is no access or barriers are too large to overcome then it does not matter what the individual's attitude is. As we discovered, many in the local area want to have nutritious diets, but the structure is such that this is a very difficult, or impossible, task. However, once a food landscape has adequate access, nutrition education is one of the most effective ways to catalyze this paradigm shift in the minds of those in the community. It remains a well-known fact that increasing nutrition education of individuals is one of the most effective methods of increasing healthy nutrition behaviors (Pem and Jeewon, 2015). Young adults are no different (Côté-Boucher, 2012), which is exciting because the earlier that healthy diet patterns are developed, the easier they are to persist into later life (Beckerman et al., 2017). Graduate students, in particular, are a population of young adults that may be more likely to latch onto education programs more so than the average 20- or 30-year olds as this group of people are naturally inclined to continue their education and be lifelong learners. The results of this survey indicate that on an individual level, there exists a gap in nutrition knowledge that education leaders and public health officials can bridge by organizing novel nutrition education programs focusing on disease prevention and positive lifetime habits. To reiterate, these programs are a proposed solution to improve the odds that individuals will choose nutritious foods in their diets. Many structural changes are also needed in the local food landscape to ensure that these programs will be as successful as they can be.

2.4.2 Perceived Barriers

One of the primary aims of this survey was to identify the existence of perceived barriers to accessing fresh and/or healthy foods in this target population. Our results are not intended to be used for generalizations of the Purdue University graduate student population as 95% of eligible survey takers did not participate. The perceived barriers discussed in this section refer only to responses from the subset of the graduate student population that took the survey. This is important to keep in mind because the population that participated most likely represents a subset of the population that cares more than the average graduate student concerning matters of food security and fresh produce availability. However, barriers to access likely affect everyone in an area whether they are interested in the topic or not. For this reason, the barriers to accessing nutritious foods provided by this subset of the population will be viewed as a pulse on the existence of the issues at hand for the majority of the population. Data that is more independent to the individual, such as fruit and vegetable consumption intake and community garden volunteering patterns, was not generalized to the whole of the graduate student population.

Upon analysis of the data, those that did choose to participate cited multiple examples of perceived barriers. Many survey respondents felt that their take-home pay and work schedules created challenges impeding them from including fresh and/or healthy foods in their diets. Even more cited a lack of healthy food options, which was often paired with poor transportation to reach those few options that do exist. Demographic information from the survey reveals that twenty-two (7.7%) American student respondents rely on public transportation, while 77 (39.3%) of international student respondents rely on public transportation. Not surprisingly, international students cited transportation issues significantly more than American students. In addition, students from developing nations cited transportation issues significantly more than students from non-developing nations. These results are yet another piece of evidence that international students face unique challenges when coming to America for higher education. Logistic challenges, such as transportation, are difficult to overcome in their own right. International students, both undergraduate and graduate, also face many unique social challenges compared to American college students. These include “academic challenges, social isolation, cultural adjustment and social isolation” (Wu et al., 2015).

Responses detailing transportation issues should not come as a major surprise as West Lafayette, Indiana and Lafayette, Indiana both score poorly on walkability tests. We know this played a significant role in how students without personal vehicles perceived the local food landscape, particularly international students. Again, the subset of survey takers were particularly interested in accessing nutritious foods so these responses provide great insight into local access to these foods because these individuals actively seek and desire such access. Below is a subset of responses that graduate students wrote concerning difficulties when accessing produce in the local area:

- “Purdue needs more food options, there are basically no healthy food options on campus. I can actually think of no healthy food options on campus, and no grocery stores at all!”
- “It is difficult to get to grocery stores around here…”
- “It's difficult to do groceries regularly without owning a car.”
- “Store is not that accessible without public transport, delivery cost is high, less availability near the campus where you can just walk and get”
- “yes, supermarket is far and public transport takes a lot of time”
- “Yes, there are no options on campus and prepared salads and meals are very expensive.”
- “Yes, because i don't have access to it where i live near Purdue campus! I need a car which I don't have and cannot afford!”
- “Other than seasonal farmers markets, there are no groceries with fresh produce within walking distance.”
- “I agree there is a lack of fresh produce available here compared to where I attended undergrad in Iowa City.”
- “I am unsatisfied with the lack of fresh grocery around campus and wish to address this issue.”
- “There are no grocery stores in walking distance of campus.”
- “While I may not suffer from food insecurity or uncertain access to food, I know that other people do and it is a serious problem that the university should work to fix.”

At the very least, the cities of West Lafayette, IN and Lafayette, IN can increase access to fresh fruits and vegetables by investing in the sidewalks of their cities. Both cities are categorized as “car-dependent” to accomplish normal chores, such as going to the supermarket. As the results of this study have shown, not every student has access to a car. When public transportation halts, as it does during the summer months and during the COVID-19 pandemic, these students suffer disproportionately.

Along with transportation, many graduate students feel their financial status negatively affects their access to fresh produce. Open-ended responses revealed that many students are stretching their stipend amount to be able to cover the cost of necessities like rent, utilities and groceries. Tuition waivers and financial assistance are wonderful resources to pay for graduate school, but many students still appear to be frustrated with their level of discretionary income. In addition, graduate students perceive their schedules to be extremely jam-packed with research, class and/or teaching responsibilities. Below are responses regarding their low pay and time requirements that make it difficult to include fresh and/or healthy foods in their diets:

- “My paycheck is barely enough to survive on and I sacrifice a healthy diet to pay my bills.”
- "It [COVID-19] has affected it A. LOT. especially because graduate students are expected to pay their normal bills as well as budget for summer on a pathetic excuse for a stipend."
- “Given my stipend amount, even on fellowship it is difficult to support myself while also affording the cost of transportation (to distant grocery stores) and rent.”
- “yes, I don't get paid enough. I'm living off of spaghetti every day”
- “I typically like to get a lot of vegetables and fruits at the stores, but now a lot of these items are out of stock or cost too much [due to COVID-19] making it very difficult to afford on a grad stipend."
- “Yes, I'm often very busy, so I rely a lot on frozen vegetables.”
- “Fresh produce is difficult to include in my diet because I need to take the time to prepare it and frequently go buy it, which I generally don't have the energy to do during the week.”

2.4.3 COVID-19 Challenges

The COVID-19 pandemic is a prime example of a modern day food shock. Many local and national food chains became disrupted, along with local public transportation and supermarket accessibility so it is no surprise that over two-thirds of survey respondents reported food purchasing being “Harder than normal” during the pandemic compared to pre-pandemic times. This is quite unfortunate because, again, nutrition is a vitally important factor for individuals to consider during a largescale public health crisis. Now, more than ever, communities need optimal access to healthy, nutrient dense foods (Butler & Barrientos, 2020). Open-ended responses that indicate the COVID-19 global pandemic created unique food purchasing challenges in the lives of graduate students:

- “hard to go to store regularly since no transport now”

- "Busses are cancelled, which means I have to carry heavy bags of groceries and walk on the highway."
- "I don't have a car and I was struggling a lot to get groceries. Buses were not running very often and I was not very confident on taking an uber."
- "All online grocery shopping now. Less produce is available online, and the produce picked out for you usually is rotten. Seems employees try to give you the worst produce they have"
- "I am curious about how graduate students can maintain healthy diets under difficult times like this where it has become significantly harder for me to obtain fresh fruits/produce."
- "Yes because graduate students have a small stipend and don't even qualify for unemployment during a national pandemic"

One piece of information that may be interesting to specialists in the industry, such as supermarket research analysts, is that the majority of graduate students did not utilize home grocery delivery services before the COVID-19 pandemic and will not utilize it more than they did before the COVID-19 pandemic. The same can be said of curbside grocery pickup services. Although, around 10% of respondents said they will utilize both of these services more after the pandemic is lifted than they did before it. Online delivery services are a promising alternative method to ameliorate some of the negative effects of a food desert, especially for students who lack access to a personal vehicle. However, these services will need to improve if more consumers are to utilize its services. Many respondents, similar to the one above, received rotten produce and no longer trust supermarket employees to pick out the best looking produce when stocking their bags for online delivery.

Individuals that choose not to utilize online services during times of market disruption are often more affected by disruptions in transportation. The CDC website agrees that transportation is a major factor when considering access to healthy food as it explicitly states, "Improving transportation options to and from such food sources as supermarkets and farmers' markets increases a community's access to healthy foods." (Center for Disease Control, n.d.). The inverse is also true in that halting transportation diminishes a community's access to healthy foods, especially during the COVID-19 pandemic. Local city planners and lawmakers need to learn from the recent public transportation shutdowns caused by the COVID-19 pandemic so that effective strategies can be implemented at the onset of the next major socioeconomic and/or public health event to avoid public transportation shutdowns.

Local community gardens are another valuable asset to utilize during times of market disruption. When utilized correctly the steady production of nutritious produce in the heart of communities directly strengthens the resilience of said communities to withstand food shocks caused by economic downturn, pandemic and most other unfortunate social circumstance. More discussion concerning community gardens and their benefits can be found in section 2.4.5.

2.4.4 Fruit and Vegetable Consumption Patterns

There does appear to be good news hidden beneath all of the struggles that graduate students face. 93% of survey respondents reported consuming adequate servings of both fruits and vegetables. The validity of 24-hour recall data is constantly under debate (Foster et al., 2019), but the aim of the survey was not to discover precise intake values in order to make largescale, sweeping declarations about the fruit and vegetable intakes of all Purdue University graduate students. What can be said is that these results suggest the encouraging news that at least some within the Purdue University graduate student population are able to overcome barriers from the rigors of graduate school, the effects of a less-than-ideal food landscape and a global pandemic. One reason could be that the students who took the survey are more interested in the topic, thus making them more likely to consume recommended levels of fruits and vegetables. As such, the participants of the survey most likely a subset of the Purdue University graduate population that over-represent students who are more conscious of the foods they are consuming. It can be reasonably assumed that these students consume fruits and vegetables in higher quantities than the average graduate student. Whether or not the remaining 95% of the Purdue University graduate student population consumes recommended servings of fruits and vegetables remains to be seen. Another explanation for this high rate of consumption could be due to social desirability bias, which posits that people over-exaggerate traits which hare perceived as positive to society. Additional surveys tracking more days of consumption or ethnographical methodologies would need to be employed to confirm our reported consumption patterns.

Another interesting discussion point that emerges from the survey data indicates that the COVID-19 pandemic did not lead to an increase in fruit and vegetable consumption for the vast majority of survey respondents. Only 16 (4%) respondents mentioned that the pandemic has affected them such that their produce consumption has increased. This fact is not unexpected when considering the issues the pandemic caused to transportation, food availability and public awareness of physically going into public to places such as the supermarket and restaurants. In fact, many survey respondents noted that they were cooking and eating more meals at home compared to pre-pandemic times. This information should be viewed as an opportunity for public health officials to educate the population on healthy cooking when dining at home. Free tutorials and recipes are available on public and government websites, but a large push could be made at this time that encourages the adoption of healthier dietary behaviors, such as prioritizing fruits and vegetables inclusion in the diet when access is available. In addition, the public could greatly benefit from programs whose aim is to scientifically and publicly discuss the advantages and disadvantages of all forms of produce (fresh, canned or frozen). The advent of such a program has great potential to help the public make better-informed decisions when shopping for fruits and vegetables and be more resilient to healthy diet disruptions when runs on fresh produce occur, for example. Benefits gained from these education programs will only be observed if nutritious foods are accessible to those who learn from them. Increasing the amount of bus routes to supermarkets, opening a grocery store closer to campus where students can more easily bike or walk to it and making sure that graduate students are always paid in a timely manner are ways to increase the resiliency of the food infrastructure so education programs can be effective and fruit and vegetable consumption rates won't suffer during difficult times.

2.4.5 Community Garden Knowledge, Motivation and Future Volunteering

Community gardens are a promising alternative method for graduate students to increase their access to locally grown fruits and vegetables (Barnidge et al., 2014) and increase the resiliency of a food landscape during food shocks. Grow Local is a network of gardeners in the greater Lafayette, Indiana area that provides ten sharing gardens that are open to the public. Produce grown on these gardens is available to anyone to take what they need. Unfortunately, three out of almost every 4 respondents said that they were either unsure that a community garden existed within a fifteen minute drive of their place of residence or that one did not exist. 95.5% of respondents said they did not volunteer at a community garden even once a year. Respondents feel that community gardens are not necessarily essential to a functioning community, but somewhat agree that they help to put food on the table of community members, increasing a community's sense of togetherness and improve the environment in which it is embedded. The majority of respondents somewhat agreed that they would be more likely to volunteer at a community garden if there was better communication of volunteering opportunities, they knew the staff were friendly and accommodating and they knew their level of gardening experience was accepted. A plurality of respondents strongly agreed that they would be more likely to volunteer at a community garden if opportunities did not conflict with their schedules and they were able to take home fresh produce from the garden. Community gardens, and other non-profit organizations that rely upon volunteers, can learn a lesson from the story that respondents told through this survey. Our results indicate that at least some Purdue University graduate students view community gardens as valuable to its community and are more likely to volunteer if there were more efficient lines of communication to them. These lines of communication should make glaringly obvious that volunteering opportunities are available for individuals of all skill levels. Survey results indicate that female respondents may respond more positively to improved lines of communication and acceptance than male students. They should also clearly communicate that fresh, locally grown fruits and vegetables are available to take home and safely consume. The majority of respondents replied that email is the best method for a community garden to convey information to them. This was followed by social media pages and text messages. Survey respondents represent a small portion of the Purdue University graduate student population, but these respondents appear to be ready and enthusiastic to volunteer at a community garden near them. In fact, 230 (59.7%) respondents said they are interested in volunteering at a community garden. Compare this to the 95% that said they never volunteer at a community garden and it is clear to see that there is untapped volunteering potential within the Purdue University graduate student population. As for COVID-19 affecting community garden volunteering, the vast majority of survey respondents said volunteering at a community garden during the COVID-19 pandemic carried very little increased risk compared to during normal times.

2.4.6 Study Limitations

Sample Size

Bujang et al. (2018) recommends that a minimum sample size of 500 is needed to derive statistics that can accurately represent the parameters of the target population. The results from our survey cannot be transposed to larger population statistics as none of the survey questions garnered 500 or more responses. Future survey research on this topic can potentially increase sample size to a minimum of 500 by sending the email blast on two separate days, thus reaching a larger group of the population. In addition, researchers may find it successful to attend department seminars and ask permission to speak directly to graduate students in person. The COVID-19 pandemic prevented this strategy from being deployed. This strategy also works to increase the variety of graduate students that respond to the survey.

Single Point of Contact

Our survey was sent to all Purdue University graduate students via email blast on only one date, Wednesday, May 20th, 2020. Because there was only one point of contact, the results of this survey represent a subset of the Purdue University graduate student population. Some students may not have been able to respond to the email on that day and the email became buried in their inbox. A second email blast was to be sent two weeks after the original, but that was not executed. In addition, there always remains a possibility that individuals who are particularly interested in the topic of food security and community gardens responded to the survey while those who do not care as much chose not to participate. This biasing has the potential to skew generalizability and the results of this study should not be used to generalize attitudes and behaviors of the Purdue University graduate student population. Similar to alleviating the effects of a low sample size, sending the survey on a second day would be a great solution to this problem. A second survey blast is likely to decrease the risk of biasing the results toward a subset of the population, as would attending department seminars as reminders to graduate students that the survey is available for them to take.

24-Hour Recall Inaccuracy

Online self-reported 24-hour dietary recall intake patterns are consistently under-reported, while 48-hour dietary recalls gather much more accurate food intake data (Foster et al., 2019). One reason is that many respondents have difficulties estimating serving sizes and frequency of consumption (Rogers, Dagnelie, 2003). Subsequent surveys can improve the accuracy of their data by utilizing a 48-hour diet recall method, by having participants keeping daily food journals, or by employing ethnography.

2.4.7 Future Works

Future research is needed to better understand the prevalence and abundance of food insecurity among the Purdue University graduate student population and the graduate student population across the nation. Much care must be taken to ensure that the results of future surveys are generalizable to the graduate student population as "survey summary statistics may not be generalizable to the target population" (Standish & Umbach, 2019). Our research project focused on the lack of access to fresh and/or healthy foods. One future research project could involve the investigation of the overabundance of Standard American Diet eating establishments in the local area. Areas containing an overabundance of such establishments are known as "food swamps." Food swamps are an important aspect to consider when examining a food landscape. In fact, food swamps are proven to be better predictors of obesity rates than food deserts (Cooksey-Stowers, 2017). While food deserts have received the lion's share of attention from policymakers on the topic of food security in the 21st century, researchers are discovering that living in neighborhoods dominated by establishments that serve SAD staples, such as fast food restaurants and convenience stores is also problematic. A study by Rose et al. (2009) coined the term "food swamp" to describe such a neighborhood. Food swamps are not as well defined as food deserts, but the term is used generally as a metaphor to describe "neighborhoods where fast food and junk food inundate healthy alternative" (Cooksey-Stowers et al., 2017). They have also been described as "geographical areas with adequate access to healthy food retail, but that also feature an overabundance of exposure to less healthy food and beverages" (National Collaborating Center for Environmental Health, 2017). Some have argued that ameliorating a neighborhood's food landscape by including more healthy options has the potential to catalyze positive dietary behaviors (USDHHS, 2019), though the truth does not appear to be as cut and dry. The prevalence and abundance of fast food and convenience stores has the potential to negate any positive effects of increased access to healthy foods. Increased availability of fast food outlets is associated with lower fruit and vegetable intake, while simultaneously encouraging the consumption of unhealthy foods (Larson, 2009). Fraser el al. (2010) discovered that the abundance of traditional Standard American Diet serving establishments, such as McDonald's, Kentucky Fried Chicken and Burger King, is greater in lower-income and minority neighborhoods. Food swamps tend to be more difficult to map graphically, so the Johns Hopkins Bloomberg School of Public Health (JHBSPH) created a map of Baltimore depicting defined food desert neighborhoods, and added common

Standard American Diet establishments to highlight these areas in Baltimore. They defined food swamps in this city with “dense clusters of circle and triangles” (Figure 2.6), and noted how food swamps and food desert appear to overlap in many areas.

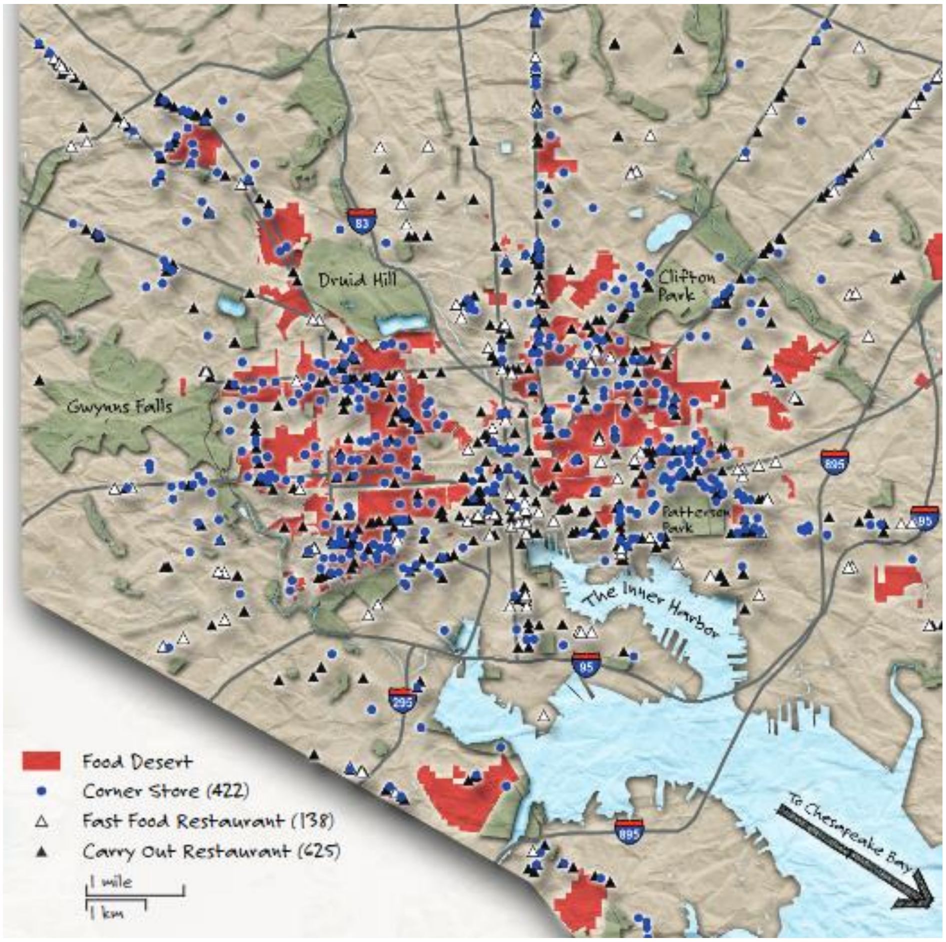


Figure 196. Map of Baltimore, Maryland’s food desert neighborhoods overlaid with corner stores, fast food restaurants and carry out restaurants (Johns Hopkins Bloomberg School of Public Health)

Purdue’s campus and surrounding region contains many SAD food establishments, so a map similar to Figure 2.6 may yield similar results. Examining the existence of a food swamp in the local area will prove useful in better defining the local food landscape when examined in tandem with the results of this research project. A more holistic understanding of the local food system allows local official and city planners to recognize where the food landscape can be improved to ensure proper access of nutritious foods to all members of the community.

2.5 References

2015-2020 Dietary Guidelines for Americans. (2020, February). 8th Edition. Retrieved from https://health.gov/our-work/food-and-nutrition/2015-2020-dietary-guidelines/

Allen, M. (2017). The sage encyclopedia of communication research methods (Vols. 1-4). Thousand Oaks, CA: SAGE Publications, Inc doi: 10.4135/9781483381411

Appelhans, B. M., Milliron, B.-J., Woolf, K., Johnson, T. J., Pagoto, S. L., Schneider, K. L., Whited, M. C., & Ventrelle, J. C. (2012). Socioeconomic status, energy cost, and nutrient content of supermarket food purchases. *American Journal of Preventive Medicine*, *42*(4), 398–402. https://doi.org/10.1016/j.amepre.2011.12.007

Azjen, Icek (1991 December) The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes.* 50(2) : 179-211. Doi: 10.1016/0749-5978(91)90020-T

Bandura, A. (1989). Human agency in social cognitive theory. American Psychologist, 44(9), 1175–1184. https://doi.org/10.1037/0003-066x.44.9.1175

Bangert, D. (2019 June 23) Purdue payroll changes leave grad students strapped, angry this summer. *Journal & Courier.* Retrieved from https://www.jconline.com/story/news/2019/06/23/purdue-payroll-changes-leave-grad-students-strapped-angry-summer/1523735001/

Barnidge, E. K., Hipp, P. R., Estlund, A., Duggan, K., Barnhart, K. J., & Brownson, R. C. (2013). Association between community garden participation and fruit and vegetable consumption in rural Missouri. International Journal of Behavioral Nutrition and Physical Activity, 10(1), 128. https://doi.org/10.1186/1479-5868-10-128

Beckerman, J. P., Alike, Q., Lovin, E., Tamez, M., & Mattei, J. (2017). The Development and Public Health Implications of Food Preferences in Children. *Frontiers in Nutrition*, *4*, 1. https://doi.org/10.3389/fnut.2017.00066

Bell et al. (2013). Access to Healthy Food and Why it Matters: A Review of the Research. *PolicyLink.* Retrieved September 14, 2020, from https://www.policylink.org/resources-tools/access-to-healthy-food-and-why-it-matters

Blitstein, J. L., Snider, J., & Evans, W. D. (2012). Perceptions of the food shopping environment are associated with greater consumption of fruits and vegetables. *Public Health Nutrition*, *15*(6), 1124–1129. https://doi.org/10.1017/S1368980012000523

Blue Book Services (2020 May 11) Produce growth stays strong, up 17%. Retrieved on September 17, 2020, from https://www.producebluebook.com/2020/05/11/fresh-produce-sales-growth-stays-strong-up-17-year-over-year/#

Bradford, V. A., Quinn, E. L., Walkinshaw, L. P., Rocha, A., Chan, N. L., Saelens, B. E., & Johnson, D. B. (2019). Fruit and vegetable access programs and consumption in low-income communities. *Journal of Hunger & Environmental Nutrition*, *14*(6), 780–795. https://doi.org/10.1080/19320248.2018.1498819

Breymeyer, K. L., Lampe, J. W., Mcgregor, B. A., & Neuhouser, M. L. (2016). Subjective mood and energy levels of healthy weight and overweight/obese healthy adults on high- and low-glycemic load experimental diets. Appetite, 107, 253-259. doi:10.1016/j.appet.2016.08.008

Burrows, J. (2020 March 20) Citybus Restricting Many Routes and Closing Main Lobby. *WLFI*. Retrieved from https://www.wlfi.com/content/news/CityBus-568970541.html

Butler, M. J., & Barrientos, R. M. (2020). The impact of nutrition on COVID-19 susceptibility and long-term consequences. *Brain, Behavior, and Immunity*, *87*, 53–54. https://doi.org/10.1016/j.bbi.2020.04.040

Center For Disease Control (n.d.) Transportation and Food Access. Retrieved September 15, 2020, from https://www.cdc.gov/healthyplaces/healthtopics/healthyfood/transportation.htm#:~:text=Transportation%20and%20Food%20Access,-Recommend%20on%20Facebook&text=Improving%20transportation%20options%20to%20and,and%20supermarket%2Dsponsored%20shuttle%20services.

Chaari, A., Bendriss, G., Zakaria, D., & McVeigh, C. (2020). Importance of Dietary Changes During the Coronavirus Pandemic: How to Upgrade Your Immune Response. *Frontiers in Public Health*, *8*, 1. https://doi.org/10.3389/fpubh.2020.00476

Claieborne, S. (2012 April 22) Practicing Resurrection: Turning Vacant Lots Into Gardens in Philadelphia. *Huffuington Post.* Retrieved from https://www.huffpost.com/entry/practicing-resurrection-t_b_1443621

Collins, M. B., Munoz, I., & JaJa, J. (2016 January 26). Linking 'Toxic Outliers' to Environmental Justice Communities. ResearchGate. Retrieved August 13, 2020, from https://www.researchgate.net/publication/292090460_Linking_%27Toxic_Outliers%27_to_Environmental_Justice_Communities

Converse, J. M., & Presser, Stanley. (1986). *Survey Questions: Handcrafting the Standardized Questionnaire (Quantitative Applications in the Social Sciences)* (1st ed.). SAGE Publications, Inc. https://books.google.com/books/about/Survey_Questions.html?id=WZ2coAEACAAJ

Costa et al., 2019 (2019 June 18). Does access to healthy food vary according to socioeconomic status and to food store type? An ecologic study. ResearchGate. https://doi.org/10.1186/s12889-019-6975-y

Davis, D. R. (2009). Declining Fruit and Vegetable Nutrient Composition: What Is the Evidence? *HortScience*, *44*(1), 15–19. https://doi.org/10.21273/hortsci.44.1.15

Duncan, G. J., & Petersen, E. (2001). The Long and Short of Asking Questions about Income, Wealth, and Labor Supply. *Social Science Research*, *30*(2), 248–263. https://doi.org/10.1006/ssre.2000.0696

Entrenas Castillo, M., Entrenas Costa, L. M., Vaquero Barrios, J. M., Alcalá Díaz, J. F., López Miranda, J., Bouillon, R., & Quesada Gomez, J. M. (2020). "Effect of calcifediol treatment and best available therapy versus best available therapy on intensive care unit admission and mortality among patients hospitalized for COVID-19: A pilot randomized clinical study." *The Journal of Steroid Biochemistry and Molecular Biology*, *203*, 105751. https://doi.org/10.1016/j.jsbmb.2020.105751

Evans, G. W., & Kantrowitz, E. (2002). Socioeconomic status and health: The potential role of environmental risk exposure. *Annual Review of Public Health*, *23*, 303–331. https://doi.org/10.1146/annurev.publhealth.23.112001.112349

Foster, E., Lee, C., Imamura, F., Hollidge, S. E., Westgate, K. L., Venables, M. C., Poliakov, I., Rowland, M. K., Osadchiy, T., Bradley, J. C., Simpson, E. L., Adamson, A. J., Olivier, P., Wareham, N., Forouhi, N. G., & Brage, S. (2019). Validity and reliability of an online self-report 24-h dietary recall method (Intake24): a doubly labelled water study and repeated-measures analysis. *Journal of Nutritional Science*, *8*, 1–9. https://doi.org/10.1017/jns.2019.20

Fraser, L. K., Edwards, K. L., Cade, J., & Clarke, G. P. (2010). The Geography of Fast Food Outlets: A Review. *International Journal of Environmental Research and Public Health*, *7*(5), 2290–2308. https://doi.org/10.3390/ijerph7052290

French, S. A., Tangney, C. C., Crane, M. M., Wang, Y., & Appelhans, B. M. (2019). Nutrition quality of food purchases varies by household income: The SHoPPER study. *BMC Public Health*, *19*(1), 231. https://doi.org/10.1186/s12889-019-6546-2

Green, D. (2020) Using R to Analyze & Evaluate Survey Data – Part 1. Datascience+. Retrieved on September 15, 2020, from https://datascienceplus.com/using-r-to-analyze-evaluate-survey-data-part-1/

Grimm, P. (2010). Social Desirability Bias. Wiley International Encyclopedia of Marketing, 1. https://doi.org/10.1002/9781444316568.wiem02057

Hebert, J.R., Clemow, L., Pbert, L. Ockene, I., & Ockene, J. K. (1995). Social Desirability Bias in Dietary Self-Report May Compromise the Validity of Dietary Intake Measures. International Journal of Epidemiology, 24(2), 389–398. https://doi.org/10.1093/ije/24.2.389

Hebert, J. R., Hurley, T. G., Peterson, K. E., Resnicow, K., Thompson, F. E., Yaroch, A. L., Ehlers, M., Midthune, D., Williams, G. C., Greene, G. W., & Nebeling, L. (2008). Social Desirability Trait Influences on Self-Reported Dietary Measures among Diverse Participants in a Multicenter Multiple Risk Factor Trial. The Journal of Nutrition, 138(1), 226S-234S. https://doi.org/10.1093/jn/138.1.226s

Institute of Medicine and National Research Council of the National Academies. (2013). *Supplemental Nutrition Assistance Program: Examining the Evidence to Define Benefit Adequacy*. https://www.ncbi.nlm.nih.gov/books/NBK206912/

Karriker-Jaffe, K. J., C. M. Roberts, S., & Bond, J. (2013). Income Inequality, Alcohol Use, and Alcohol-Related Problems. *American Journal of Public Health*, *103*(4), 649–656. https://doi.org/10.2105/AJPH.2012.300882

Krebs-Smith, S. M., Guenther, P. M., Subar, A. F., Kirkpatrick, S. I., & Dodd, K. W. (2010). Americans Do Not Meet Federal Dietary Recommendations. *The Journal of Nutrition*, *140*(10), 1832–1838. https://doi.org/10.3945/jn.110.124826

Kruskal, W. H., & Wallis, W. A. (1952). Use of Ranks in One-Criterion Variance Analysis. *Journal of the American Statistical Association*, *47*(260), 583–621. https://doi.org/10.1080/01621459.1952.10483441

Kye, S., Kwon, S.-O., Lee, S.-Y., Lee, J., Kim, B. H., Suh, H.-J., & Moon, H.-K. (2014). Under-reporting of Energy Intake from 24-hour Dietary Recalls in the Korean National Health and Nutrition Examination Survey. Osong Public Health and Research Perspectives, 5(2), 85–91. https://doi.org/10.1016/j.phrp.2014.02.002

Laerd Dissertation (n.d.) Total Population Sampling. Retrieved on September 15, 2020 from http://dissertation.laerd.com/total-population-sampling.php

Lafayette, IN Rental Market Trends. (2020 February) Retrieved from https://www.rentcafe.com/average-rent-market-trends/us/in/lafayette/

LaCaille, L., Patino-Fernandez, A. M., Monaco, J., Ding, D., Upchurch Sweeney, C. R., Butler, C. D., Soskolne, C. L., Gidron, Y., Gidron, Y., Turner, J. R., Turner, J. R., Butler, J., Burns, M. N., Mohr, D. C., Molton, I., Carroll, D., Critchley, H., Nagai, Y., Baumann, L. C., … Söderback, I. (2013). Eating Behavior. *Encyclopedia of Behavioral Medicine*, 641–642. https://doi.org/10.1007/978-1-4419-1005-9_1613

Low, Sarah A., Aaron Adalja, Elizabeth Beaulieu, Nigel Key, Steve Martinez, Alex Melton, Agnes Perez, Katherine Ralston, Hayden Stewart, Shellye Suttles, Stephen Vogel, and Becca B.R. Jablonski. (2015 January). Trends in U.S. Local and Regional Food Systems, AP-068, U.S. Department of Agriculture, Economic Research Service.

National Collaborating Centre for Environmental Health. (2017). Food Deserts and Food Swamps: A Primer. Retrieved September 15, 2020, from https://www.ncceh.ca/sites/default/files/Food_Deserts_Food_Swamps_Primer_Oct_2017.pdf

MacQueen, K. M., McLellan, E., Kay, K., & Milstein, B. (1998). Codebook Development for Team-Based Qualitative Analysis. CAM Journal, 10(2), 31–36. https://doi.org/10.1177/1525822x980100020301

Mcdermott, M. S., Oliver, M., Svenson, A., Simnadis, T., Beck, E. J., Coltman, T., . . . Sharma, R. (2015). The theory of planned behaviour and discrete food choices: A systematic review and meta-analysis. International Journal of Behavioral Nutrition and Physical Activity, 12(1). doi:10.1186/s12966-015-0324-z

McNaught, C., & Lam, P. (2010). Using Wordle as a Supplementary Research Tool . The Qualitative Report, 15(3), 630-643. Retrieved from https://nsuworks.nova.edu/tqr/vol15/iss3/8

Medelyan, A. (2020) Coding Qualitative Data: How to Code Qualitative Research. Retrieved on September 15, 2020, from https://getthematic.com/insights/coding-qualitative-data/

Michimi, A., & Wimberly, M. C. (2010). Associations of supermarket accessibility with obesity and fruit and vegetable consumption in the conterminous United States. *International Journal of Health Geographics*, *9*, 49. https://doi.org/10.1186/1476-072X-9-49

Move.org (2020 Sep. 3) Utility Bills 101: Utilities Tips, Average Costs, Fees, and More. Retrieved from https://www.move.org/utility-bills-101/

Payne, B. K., Brown-Iannuzzi, J. L., & Hannay, J. W. (2017). Economic inequality increases risk taking. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(18), 4643–4648. https://doi.org/10.1073/pnas.1616453114

Pechey, R., & Monsivais, P. (2016). Socioeconomic inequalities in the healthiness of food choices: Exploring the contributions of food expenditures. *Preventive Medicine*, *88*, 203–209. https://doi.org/10.1016/j.ypmed.2016.04.012

Pem D, & Jeewon R. (2015). Fruit and Vegetable Intake: Benefits and Progress of Nutrition Education Interventions- Narrative Review Article. Iran J Public Health. 44(10):1309-21. PMID: 26576343; PMCID: PMC4644575.

Peterson, L., Johannsson, V., & Carlsson, S. G. (1996). Computerized testing in a hospital setting: Psychometric and psychological effects. *Computers in Human Behavior*, *12*(3), 339–350. https://doi.org/10.1016/0747-5632(96)00012-x

Peterson, N. D., & Freidus, A. (2020). More than Money: Barriers to Food Security on a College Campus. *Culture, Agriculture, Food and Environment*, 1. https://doi.org/10.1111/cuag.12252

Polit, D. F., & Beck, C. T. (2010). Generalization in quantitative and qualitative research: Myths and strategies. International Journal of Nursing Studies, 47(11), 1451–1458. https://doi.org/10.1016/j.ijnurstu.2010.06.004

Purdue Dining (n.d.). Nutrition and Wellness. Retrieved September 14, 2020, from https://dining.purdue.edu/Allergies-Nutrition/index.html

Purdue University Graduate Student Salaries. (2020 Sep 14) Retrieved from https://www.glassdoor.com/Salary/Purdue-University-Graduate-Student-Salaries-E23491_D_KO18,34.htm

Razdan, K., Singh, K., & Singh, D. (2020). Vitamin D Levels and COVID-19 Susceptibility: Is there any Correlation? *Medicine in Drug Discovery*, *7*, 100051. https://doi.org/10.1016/j.medidd.2020.100051

Rent Café (2020) Lafayette, IN Rental Market Trends. Retrieved on September 17, 2020, from https://www.rentcafe.com/average-rent-market-trends/us/in/west-lafayette-city/

Rent Café (2020) West Lafayette City, IN Rental Market Trends. Retrieved on September 17, 2020, from https://www.rentcafe.com/average-rent-market-trends/us/in/west-lafayette-city/

Rogers, K. (2015, December 6). *Food desert | Britannica*. Food Desert. Retrieved September 14, 2020, from https://www.britannica.com/topic/food-desert

Rose, D., Bodor, J. N., Hutchinson, P. L., & Swalm, C. M. (2010). The Importance of a Multi-Dimensional Approach for Studying the Links between Food Access and Consumption. *The Journal of Nutrition*, *140*(6), 1170–1174. https://doi.org/10.3945/jn.109.113159

Russell, H. (2011). RESEARCH METHODS IN ANTHROPOLOGY 5ED: Qualitative And Quantitative Approaches (Fifth ed.). Bernard University Of Florida. AltaMira Press.

Sakshaug, J. W., & West, B. T. (2014). Important Considerations When Analyzing Health Survey Data Collected Using a Complex Sample Design. American Journal of Public Health, 104(1), 15–16. https://doi.org/10.2105/ajph.2013.301515

Shahar, D., Shai, I., Vardi, H., Shahar, A., & Fraser, D. (2005). Diet and eating habits in high and low socioeconomic groups. *Nutrition (Burbank, Los Angeles County, Calif.)*, *21*(5), 559–566. https://doi.org/10.1016/j.nut.2004.09.018

Siahpush, M., Singh, GH., Jones, PR., Timsina, LR. (2009 Nov. 5). Racial/ethnic and socioeconomic variations in duration of smoking: results from 2003, 2006 and 2007 Tobacco Use Supplement of the Current Population Survey. *Journal of Public Health,*

Standish, T., & Umbach, P. D. (2018). Should We Be Concerned About Nonresponse Bias in College Student Surveys? Evidence of Bias from a Validation Study. *Research in Higher Education*, *60*(3), 338–357. https://doi.org/10.1007/s11162-018-9530-2

Suter, C. (2018 Jan. 7) Campus food security suffers a hit. *Purdue Exponent*. Retrieved from https://www.purdueexponent.org/campus/article_b812c59e-7ab2-5c17-969a-82aa670dd189.html#:~:text=The%20study%20found%20that%20while,often%20flies%20under%20the%20radar

Tucker, K. L. (2007). Assessment of usual dietary intake in population studies of gene–diet interaction. *Nutrition, Metabolism and Cardiovascular Diseases*, *17*(2), 74–81. https://doi.org/10.1016/j.numecd.2006.07.010

U.S. Department of Health and Human Services (n.d.). CED Healthy Food Financing Initiative FY 2016. Retrieved September 14, 2020, from https://www.acf.hhs.gov/ocs/programs/community-economic-development/healthy-food-financing

USDA ERS (n.d.). Food access. Retrieved September 14, 2020, from https://www.ers.usda.gov/data-products/food-access-research-atlas/documentation/

USDA ERS (n.d.). Food Security and Nutrition Assistance. Retrieved September 14, 2020, from https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/food-security-and-nutrition-assistance/

USDHHS. (2019, July 20). *CED Healthy Food Financing Initiative FY 2016*. Office of Community Services | ACF. https://www.acf.hhs.gov/ocs/programs/community-economic-development/healthy-food-financing

University of California San Diego (2019) Classification: Lumping & Splitting. Retrieved on September 15, 2020, from https://pages.ucsd.edu/~dkjordan/resources/clarifications/Th-Lumpers.html

Ventola C. L. (2011). Direct-to-Consumer Pharmaceutical Advertising: Therapeutic or Toxic?. P & T : a peer-reviewed journal for formulary management, 36(10), 669–684.

Wang, D. D., Leung, C. W., Li, Y., Ding, E. L., Chiuve, S. E., Hu, F. B., & Willett, W. C. (2014). Trends in Dietary Quality Among Adults in the United States, 1999 Through 2010. *JAMA Internal Medicine*, *174*(10), 1587–1595. https://doi.org/10.1001/jamainternmed.2014.3422

West Lafayette City, IN Rental Market Trends. (2020 February) Retrieved from https://www.rentcafe.com/average-rent-market-trends/us/in/west-lafayette-city/

Young, L. R., & Nestle, M. (2009). Portion Sizes in Dietary Assessment: Issues and Policy Implications. *Nutrition Reviews*, *53*(6), 149–158. https://doi.org/10.1111/j.1753-4887.1995.tb01542.x

CHAPTER 3. LEAF COMPOST & T. HARZIANUM EFFECTS ON TOMATO PLANT VITALITY, PRODUCTION AND INDUCED SYSTEMIC RESISTANCE

3.1 Introduction

The world's leading independent assessment on the state of global nutrition, The Global Nutrition Report (GNR), states that "progress on malnutrition is not just too slow, it is also deeply unfair." The Food and Agriculture Organization of the United Nations (FAO) details in the 2019 version of its annual *State of Food Security and Nutrition in the World* that around 820 million people around the world live in a state of chronic hunger. Even more startling, estimates show that over 2 billion people do not have regular access to safe, nutritious and sufficient food (FAO, 2019). Paradoxically, individuals who suffer from malnutrition can be either underweight or obese. Statistics show that one in every nine people around the world is hungry while one in three is overweight or obese. (Global Nutrition Report, 2020) Steiner et al. find in their review of hunger and obesity rates that "Diet quality [is] one of the prime culprits for the paradoxical co-existence of two opposite states on the food security scale." For example, 37% of people living in the district of South Bronx in New York City struggle to purchase food and yet this very district consistently leads the nation in obesity rates (Steiner et al, 2019). Lower economic status correlates to an increased consumption of grains, added sugars and fats as they are "inexpensive, good-tasting and convenient" (Drewnowski, 2012).

In other words, the current state of global nutrition is following dangerous trends on two ends of the spectrum. On one end, food insecure families do not have consistent access to the proper amount of calories, leading to malnutrition and hunger. At the same time, in the Western world where access to food is more prevalent, poorer individuals are purchasing cheap, energy-dense foods lacking in nutrients, thus greatly increasing their risk of gaining excessive weight. In many cases, as Steiner et al. (2019) point out, lower socioeconomic individuals are both at increased risk to be obese and hungry.

Swinburn et al. (2019) classified the perpetuation of food insecurity, malnutrition and obesity in the modern world as a "syndemic", or synergy of epidemics. The term "syndemic" was created well over a year before the COVID-19 pandemic took center stage in 2020 (Swinburn, 2019). The negative effects of the current COVID-19 pandemic on global food security and malnutrition are significant and widespread, specifically in communities that are most vulnerable (Huizar et al., 2020). Governments across the globe have mandated quarantines, shelter-in-places and lockdowns as tactics to prevent the spread of the virus among citizens. These measures to contain the disease have had the unintended consequence of causing collateral damage to an already imperfect and stressed global food system. Huizar et al. (2020) state that response to the pandemic has the potential to "further vulnerabilities to food insecurity, malnutrition and obesity." The World Bank writes that food security during the COVID-19 pandemic is primarily affected by domestic food chain disruptions including food price inflation, loss of incomes and disruptions to inputs such as fertilizers, seeds or labor shortages, which could have a strong negative effect on growing seasons in the near future. The COVID-19 pandemic and the response thereafter in the United States has led to a "98% increase in the demand and reliance on receiving food from local food banks" (Feeding America, 2020) and increases in the enrollment of the Supplemental Nutrition Assistance Program (SNAP) (Center on Budget and Policy Priorities, 2020), formerly food stamps, and the Supplemental Nutrition Program for Women, Infants and Children (WIC) (USDA, 2020).

The COVID-19 pandemic has provided evidence of food security's identity as a connected web of interdisciplinary research fields that is not impervious to social, political, economic and environmental shocks. Agriculture is not only affected by these sectors, it is necessary for the sustainability of these sectors and managing agriculture's role is becoming increasingly important for the sustainability of modern society as a whole. There are many topics to consider when assessing agriculture's ever-increasing importance as the 21st century trudges on. However, there are three main focal points to be addressed that will help provide context for the importance and necessity of researching microbial inoculants and leaf composting in agricultural production. These three focal points are: rising global and urban population, climate change and degrading soil quality.

The current global population hovers around 7.67 billion and the United Nations estimates that the world population will reach "9.7 billion in 2050 and could peak at nearly 11 billion around 2100." (United Nations, 2019) Rising populations are causing major issues to the American and global food systems as access and distribution systems become increasingly stressed (Satterthwaite, 2010). By 2050, 68% (6.6 billion) of the world's population is expected to live in urban settings. This is a substantial increase from the current level of 55% (United Nations, 2018). Figure 3.1

depicts the rise in global urban population from 1960-2015 based on estimates from the World Bank. Note that the urban population has more than quadrupled during this time from around 1 billion in 1960 to over 4 billion in 2015 (Figure 3.1).

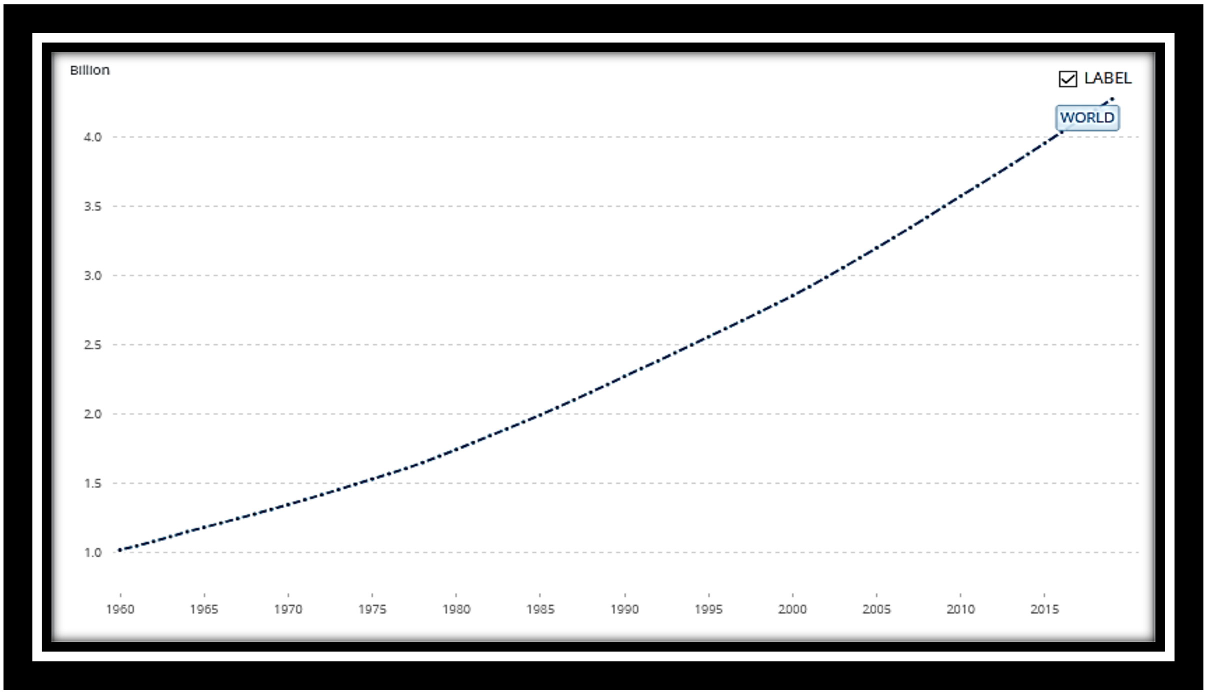


Figure CHAPTER 3.1. Global urban population, 1960-2015 (World Bank)

Urban growth is projected to be the most rapid in low- and lower-middle-income nations (United Nations, 2018). Sustainably developing these increasingly crowded urban areas is a monumental task. Rapid urbanization poses a giant challenge for "sustainable, safe and nutritious food provisioning: food security has entered the urban agenda" (Wertheim-Heck et al., 2019). The poorest members of urban households are at the greatest risk of experiencing food insecurity. For example, low-socioeconomic urban Nepalese and Cambodian citizens have little to no access to nutritious foods and still can spend nearly all of their wages on food (Boonyabancha, 2019). Urban food insecurity among the poor has also been documented in other major cities including Hanoi, Vietnam (Wertheim-Heck, 2019), Cape Town, South Africa (Battersby, 2011) and New York City (Karnik, 2011). Not coincidentally, urban agriculture production is on the rise worldwide. Research shows that access to fresh fruits and vegetables for urban residents can increase with proper planning and management of urban agricultural endeavors (Lee Smith, 2010; Maxwell et al., 1998; Alaimo et al., 2008). However, food produced in urban settings does not always directly lead to increased access of fruits and vegetables for urban residents. Physical proximity, cost of food, cost of land, cultural acceptability, and nutrition education are all barriers to accessing urban produced foods (Siegner, 2018).

Urban farm operations are also at an increased risk of producing food on contaminated soils as a consequence of anthropogenic pollution (De Kimpe, 2000). While Western world urban consumers increasingly prefer locally grown produce (Hesterman and Horan, 2017), rapid urbanization has catalyzed an increase in both peri-urban land prices and housing demand (Zasada, 2011). Farmers are then forced to compete with the rising demand for housing developments. In the 20 years between 1992 and 2012, the United States alone lost 31 million acres of farmland to development, with 11 million of those acres occupying land with "superior soil conditions and weather for growing food" (American Farmland Trust, 2020). The American Farmland Trust developed the figure below (Figure 3.2) to easily visualize development on agricultural land from 1992-2012.

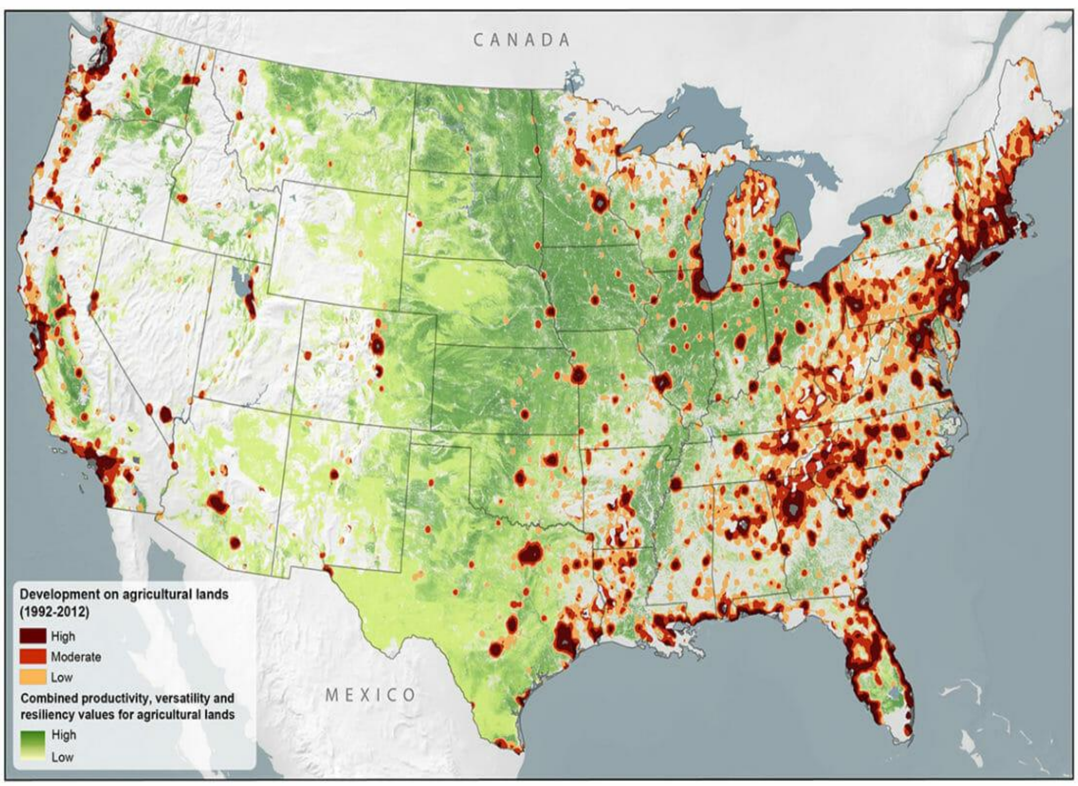


Figure CHAPTER 3.2. The conversion of agricultural land to urban and low-density residential development between 1992 and 2012. (American Farmland Trust)

Climate change is also a serious issue to be dealt with by the agricultural community (Ziska, 2016). According to the United States government's National Oceanic and Atmospheric Administration, land and ocean temperatures have increased 0.07°C (0.13°F) per decade since 1880. Since 1981 that rate has more than doubled to 0.18°C (0.32°F) per decade (Lindsey and Dahlman, 2020). Temperature increases have already begun to cause significant impacts on yields of certain crops approaching the upper limits of their optimal temperature for growth and reproduction (Lobell, 2013; Peng, 2004; Zhao, 2017). Rising temperatures also favor the growth of tolerant weeds (Hatfield et al., 2014). In addition, rising atmospheric CO_2 levels have been associated with "reduced protein and nitrogen content in alfalfa and soybean plants, resulting in loss of quality" (Hatfield, J, 2014) and a "reduction in nutritional value of most food crops" (Beach et al., 2019). While the "climate" portion of climate change refers to long-term meteorological patterns, climatologists are also observing short-term weather pattern invariability (MacDonald, 2010; Mallakpour and Villarini, 2015; Bell, et al., 2016). Planning for future agricultural activities is much more difficult when both length and weather conditions of a growing season become increasingly unpredictable. In addition, research shows that climate change has affected the strength and abundance of extreme weather events (Seneviratne et al., 2012). Extreme weather events, such as flooding, hurricanes and drought, can dramatically harm crop yields in a growing season. These extreme weather events can happen in the blink of an eye. Just recently, an estimated 43%, or 10 million acres, of corn and soybean crops were flattened in the midwestern state of Iowa in August of 2020 from a storm containing winds exceeding 100 mph (Cappucci, M., 2020). Figure 3.3 depicts major dips in American corn yields from 1960-2009 and the corresponding major meteorological events that occurred.

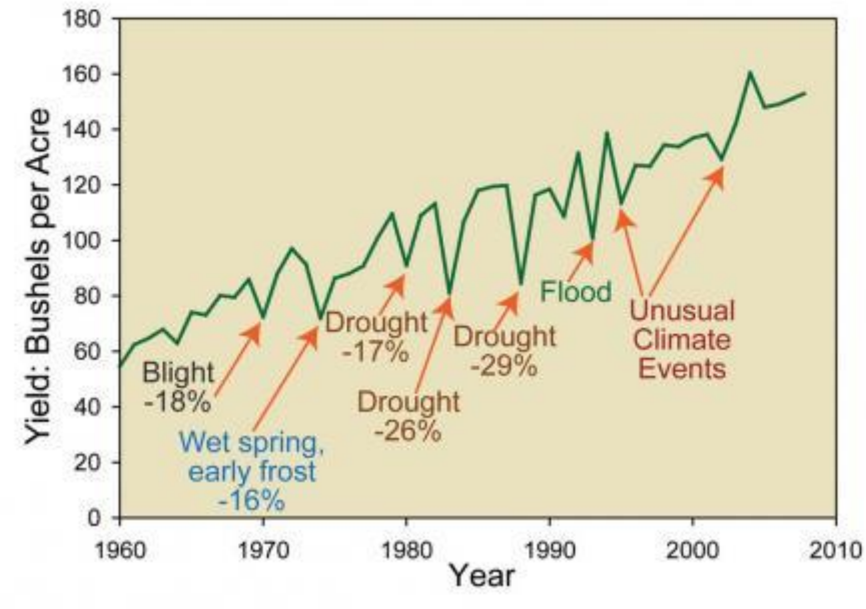


Figure CHAPTER 3.3. Extreme weather events and their effects on American corn yields, 1960-2009 (GlobalChange.gov)

Nearly every sector in modern society is facing the enormous task of mitigating its negative effects on the environment and agriculture is no different. The Agricultural Revolution of the mid-1880’s led to many advances in the technology of fertilizers, pesticides, cultivation and breeding. Production has since made enormous leaps and bounds, especially in the post-World War II period of 1950-1975. The Green Revolution of the late 20th century undoubtedly brought about technologies that increased yields of many crops to a level that could allow the population of certain at-risk nations like India and Mexico to grow as it has in this modern epoch (Pingali, 2012). But at what cost? As the old adage goes: there’s no such thing as a free lunch. This increase in production has not been made without tradeoffs, especially with the environment. The United States Environmental Protection Agency (EPA) estimates that 10.5% of total U.S. greenhouse gas emission and 24% of global greenhouse gas emissions are released by the agriculture and forestry sector (Environmental Protection Agency, 2020). Increased application of fertilizer and pesticides has also influenced the environment. Agricultural runoff is especially vulnerable to leaching nitrogen as its nitrate form is highly soluble (Sharpley et al., 1987). Two-thirds of the Mississippi River’s nitrogen content comes from fertilizer and manure use on agricultural lands (Ribaudo, 2006). Consistent nitrogen loads from the Mississippi River have fueled large populations of algae and plankton to flourish in the Northern portion of the

Gulf of Mexico. Once these organisms die, their decay “robs the water of oxygen” leading to a hypoxic zone covering 7,000 square miles, or the size of New Jersey (Ribaudo, 2006; Van Meter, 2018).

Agricultural management practices also influence the environment. Increasingly intensive agriculture and monoculture practices, the agricultural practice of growing a single crop year after year on the same land, have made for an increased risk of crop damage due to pest and disease (Bianchi, 2006; Segoli and Rosenheim, 2012). Not coincidentally, the utilization of pesticides increased around ten times from 1945-1985 (Trauttman et al., n.d.). While pesticide application has undoubtedly protected crop loss and aided in controlling vector-borne disease, their widespread use has also been shown to have negative consequences on human health (Aktar et al., 2009; Costa, 2008), contamination of surface water (Kole et al., 2001; United States Geological Survey, n.d.) and rapid pest resistance (Hawkins et al., 2018; Maino et al., 2018).

Unfortunately, intensive agricultural practices, as well as contaminants from the industrial sector and urban areas, have depleted the health of soils worldwide (Kopittke, 2019; Eswaran et al., 2019; Jie et al., 2002). Soils not only provide short-term benefits to human populations (i.e. food production, fiber production, renewable energy production), they also provide long-term benefits (i.e. carbon dioxide sinks, flood prevention) (Kopittke, 2019). McBratney et al. (2017) estimated the total value of all ecosystem services provided by soils worldwide to be $11.4 trillion. Estimates show that “33% of soils are presently moderately to highly degraded due to erosion, salinization, acidification, contamination or compaction” (FAO, 2015). Other estimates show that “52% of agricultural land is moderately or severely affected by soil degradation” (Noel et al., 2015). Soil degradation could reduce global food productivity by as much as 12%, leading to an increase in food prices by 30% (Noel et al., 2015).

The practices of tilling and pesticide application are especially disadvantageous for supporting and sustaining a soil’s organic matter content. Soil organic matter (SOM) is a vitally important component of the soil for a plethora of reasons. SOM “serves as a reservoir of nutrients for crops, provides soil aggregation, increases nutrient exchange, retains moisture, reduces compaction, reduces surface crusting, and increases water infiltration into soil” (USDA NRCS, n.d. b). SOM also supports a thriving soil microbiome that helps to detoxify contaminants and suppress disease-causing pathogens (Ochoa-Hueso, 2017). Conventional tilling of the soil destroys soil aggregation, which is “the habitat soil microorganisms depend upon to ensure critical soil functions like nutrient cycling" (USDA NRCS, n.d. c) and oxidizes SOM, leading to an accelerated release of carbon dioxide from the soil (Al-Kaisi, 2002). In short, conventional tilling turns a soil from a sink to a source of atmospheric carbon pollutants (Busari et al., 2015), thereby decreasing soil C stocks and overall SOM (Haddaway et al., 2017). Annual pesticide application, while useful, also leads to decreased overall SOM (Kalia and Gosal, 2011). Living organisms in the soil suffer from the excessive use of fungicides (Smith et al., 2000), insecticides (Patnaik et al., 1996; Sannino and Gianfreda, 2001; Meena et al., 2020) and herbicides (Milosevic and Govedarica, 2002; Kremer and Means, 2009).

The rate of soil erosion worldwide far outpaces the rate at which soil is generated (Eswaran, 2019; Kopittke, 2019). 2015 estimates show that 20-30 gigatons (1,000,000,000 tons) of soil are lost annually worldwide from wind erosion while around 5 gigatons of soil are lost annually to tillage erosion (FAO, 2015). This rate of loss is 10-1,000 faster than the rate at which soil forms (Kopittke, 2019). Reductions in soil volume lowers the ability for water to be stored for plant use. In fact, around a 4% decrease in yields results after a loss of only 10 cm of soil, largely due to its decreased ability to hold onto water (FAO, 2015). Soil erodes primarily in the nutrient-rich topsoil layer. Loss of nutrients in a soil means a farmer must increase the utilization of fertilizers to sustain yield levels (Kopittke, 2019). Nitrogen (N) loss is of particular importance to farmers. N fertilizers are the most important fertilizer in modern agriculture and their use has increased tremendously from 1960 to the present (Figure 3.4).

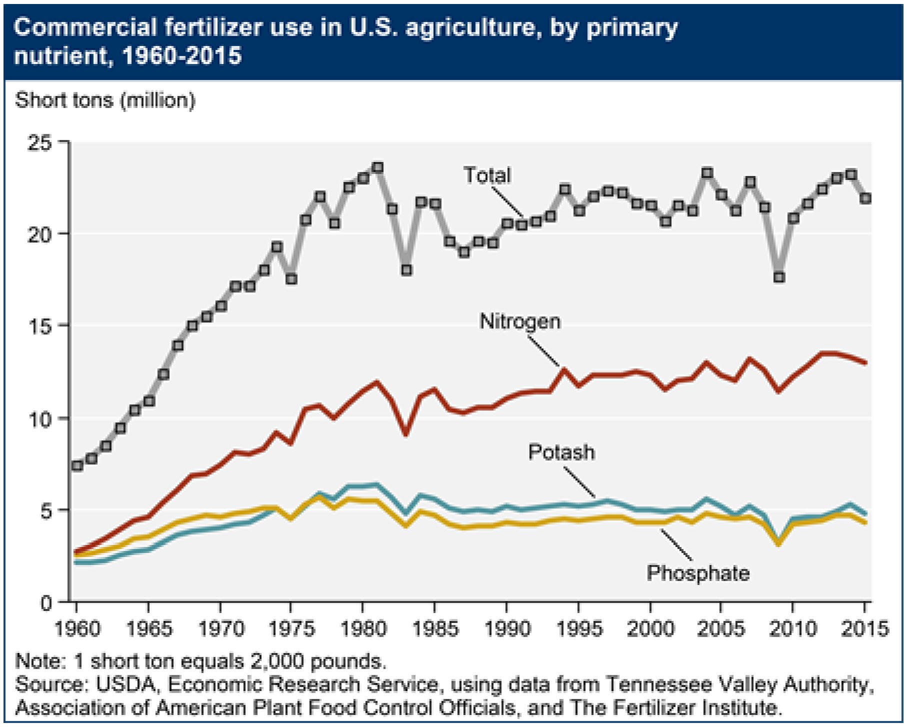


Figure CHAPTER 3.4. US commercial fertilizer use, 1960-2015 (USDA ERS)

N fertilizer efficiency decreases as use increases and estimates show less than half (47%) of the N fertilizer applied in 2010 was taken up by plants (Lassaletta et. al., 2014). Fertilizer not taken up by the plants often ends up leaching to undesired locations and/or acidifies the soil (Rengel et al., 2000). Fertilizers are not the only mechanism through which soils become contaminated. Other mechanisms include: contaminated irrigation water, pesticide application, contaminated wastes used for land application and industrial by-products (Kopittke, 2019). Humans and plants are faced with an increased risk of health damage when soils become increasingly contaminated (Rodrigues and Romkens, 2018; Lu et al., 2015).

In short, agriculture is being called upon to feed more mouths, on less land that contains depleted soils and in increasingly challenging climatic conditions. All the while reducing its greenhouse gas emissions and runoff of pollution on increasingly thin budget margins (Gloy et al., 2015). This is a Herculean task, but not an impossible one.

Sometimes solutions to the world's biggest problems are discovered by thinking small. Microorganisms are some of the smallest and most numerous living organisms on Earth. A soil's microbiome consists of all bacteria, fungi, viruses, protozoa and archaea present. The importance of the soil microbiome to plant health and food production cannot be understated. Each member plays a vital role in the soil's ability to sustain "biogeochemical cycling, plant growth and carbon sequestration" (Dubey et al., 2019). Fungi are a particularly interesting and important group of soil microbes. Fungi are eukaryotic and contain membrane-bound cells with organelles like the DNA-housing nucleus and energy-producing mitochondria. Compared to bacteria, fungi are better able to decompose and absorb nutrients from lignin and other harder-to-breakdown SOM (Hoorman, 2016). This is done by their ability to secrete a mixture of digestive enzymes onto potential food sources and absorb the newly-soluble substrates into their cells, thus allowing them to metabolize contents (Druzhinina et al., 2018). Fungi can be single-celled, like yeast, or multi-cellular. Multi-cellular fungi grow in the form of cylindrical hyphae that are divided into separate cells. These hyphae intertwine with one another to form the main body of the fungus, or mycelium. These mycelium occupy large amounts of surface area in the soil. Mycelium produce enzymes that act on SOM and mineral compounds to release the nutrients and energy the fungus needs to grow (Riquelme et al., 2018). Others can interact directly with plant roots to help plants acquire resources and withstand biotic and abiotic stress.

Arbuscular mycorrhizal fungi (AMF) are one of the most well-studied group of fungi that interact with plants to positively impact their health and productivity. AMF are a specially evolved family of fungi of the Basidiomycota phylum that have developed a symbiotic relationship with over 90% of green plants worldwide over time (Asmelash et al., 2016). These plants experience enhanced photosynthetic rates (Birhane et al., 2012), increased water uptake and resistance to stresses such as drought, high salinity levels, herbivory, temperatures, metals and diseases when AMF are present (Abdel-Fattah et al., 2014; Asrar, 2011). In fact, up to 80% of the nitrogen and phosphorous taken up by plants involved in this symbiotic relationship is provided by AMF (Behie and Bidochka, 2013; van der Heijden et al., 2015). AMF provide these functions by forming hyphal networks within cortical cells of vascular roots and extending into the surrounding rhizosphere where they can forage for nutrients and translocate them to the root (Figure 3.5) (Begum et al., 2019). The efficiency of nutrient scavenging by AMF depends on plant and fungus type, nutrient availability (Bitterlich et al., 2018) and atmospheric CO_2 concentration (Maĉek, 2019). These variables create challenges when considering the possibility of further up-scaling commercial utilization of beneficial microbes like AMF to enhance agricultural productivity (Thrikell et al., 2017).

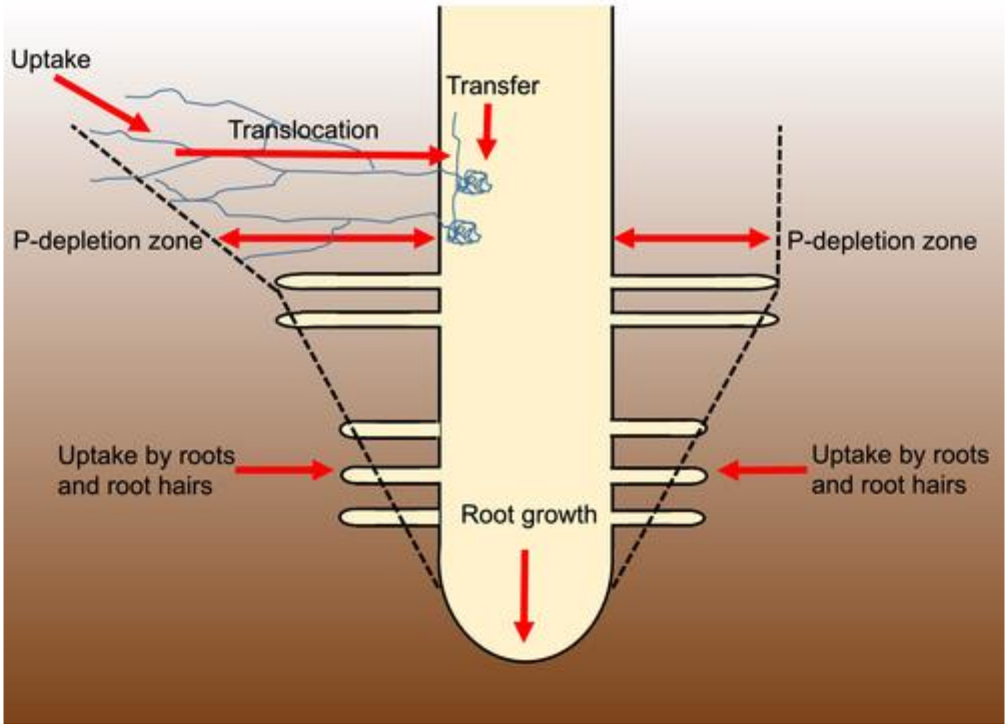


Figure CHAPTER 3.5. Mycorrhizal and direct (non-mycorrhizal) P uptake pathways. (Smith and Smith, 2011)

Legume farmers worldwide are well aware of the symbiotic relationship between diazotrophic rhizobia and roots of host plants. These rhizobia biologically fix enough nitrogen to supply the plant with all of its N needs, thus eliminating the need for farmers to amend the soil with nitrogen fertilizers.

Agricultural scientists have been designing microbial inoculants to introduce beneficial microbes to plants for over 100 years. Microbial inoculants are amendments that introduce beneficial microbes to the roots of plants or the surrounding rhizosphere to support agricultural production and increase sustainability. The world's biggest agricultural companies are understanding the need and the demand for microbial inoculants and millions upon millions of dollars are being invested into the commercialization of microbial inoculants (Wallenstein, 2017). These beneficial microbes provide a wide array of benefits to the plant including, but not limited to, plant growth, the production of phytohormones, siderophores, phosphate solubilization and induction of plant intrinsic systemic resistance to abiotic and biotic stress (Bhattacharyya and Jha, 2011). The first patent for developing microbial inoculants was awarded in 1896 and "Nitragin" hit the market for commercial use. *Azospirillum* are another example of a commercially used diazotrophic bacteria utilized to meet a plant's N demand (Zeffa et al., 2019). By the turn of the century, research and investment investigating the role that microorganisms in the rhizosphere play led to the discoveries of the "rhizosphere effect" (Hiltner, 1904), the protection of roots against soil-borne pathogens (Cook et al., 1995, Weller et al., 2002) and the communication that exists between microorganisms and their host plant (Ryu et al., 2003, Hartmann and Schikora, 2012). Also discovered were tailored plant exudates of amino acids and carbohydrates to recruit specific and support beneficial microorganisms (Moe, 2013, Weston and Mathesius, 2013). Plants understand the deeply critical function that microorganisms play in their growth and well-being.

One important fungal genus being researched for its abilities as a biological control agent are *Trichoderma spp.* This genus of fungi is present in most soils worldwide and is often the most prevalent culturable fungi in soil (Herman, n.d.). *Trichoderma* species members are unique fungi in that they can acquire nutrients from other living fungi (Druzhinina, 2011), plants (Li, 2014) animals and even immunocompromised humans (Gautheret, 1995). They are also able to survive in soil as saprophytes by feeding on dead fungi and decomposing plant debris (Druzhinina, 2011). Similar to AMF, *Trichoderma* strains colonize plant roots by penetrating the outermost layers of the root's epidermis and colonizing intracellular spaces, even growing between the cell wall of a plant cell and the plasma membrane (Yedidia et al., 1999; Nogueira-Lopez et al., 2018). Several hundred separate plant genes that affect protein expression are altered with root colonization of *Trichoderma* species, with the majority of altered gene expression in the shoots of colonized plants rather than the roots (Shoresh et al., 2010).

Trichoderma strains are used as biological control agents for both their direct and indirect mechanisms of actions. These fungi directly outcompete pathogens for space and nutrients and aggressively parasitize competitors through the production of hydrolytic enzymes and/or metabolites (Harmen, GE 2004; Vinale et al., 2008). *Trichoderma* genus members compete specifically with plant pathogenic fungi and oomycetes (Debbi et al., 2018), but predation has also been observed against harmful bacteria, viruses, insects and nematodes (Coppola et al., 2017; Elsharkawy et al., 2013). Indirectly, plants inoculated with *Trichoderma* trigger an increased defense response known as induced systemic resistance (ISR) (Moran-Diez et al., 2020; Shoresh, 2010; Hermosa, 2012; Cordo et al., 2007), that further protects the plant from soil-borne and foliar pathogens. ISR is thought to be mediated by jasmonic acid (JA) and ethylene (ET) pathways (Ramirez-Valespino, 2019). However, this is likely to be more complex, as studies have shown that *Trichoderma* colonizes JA-impaired *Arabidopsis* plants just as much as wild-type plants with functioning JA-producing systems (Martinez-Medina et al., 2016a). Salicylic acid (SA) pathways are expected to prevent certain *Trichoderma* species from colonizing vascular root systems (Alonso-Ramirez, 2014), thereby helping the plant keep the fungus in check. Interestingly, *Trichoderma* species have even been found to induce both the fast-acting SAR and ISR plant defense pathways when under attack from nematodes (Martinez-Medina et al., 2016b), further demonstrating the complexity of this plant-microbial relationship.

T. harzianum is one of the most important species within the *Trichoderma* genus for use as a biological control agent (Sofo et al., 2012). Mechanisms of biological control include chemiotropic mycoparasitic interactions with target pathogenic fungi (Sahebani and Hadavi, 2008), excretion of mycolytic cell wall degrading chitinases and β-1,3 glucanases, (Ferreira and Ferreira Filho, 2004; Harman, 2006) enhanced root growth leading to healthier plant development (Harman, 2000; Sofo et al., 2010; Kleifeld and Chet, 1992) and ISR (De Meyer, 1998). In addition, the application of *T. harzianum* and AMF in tandem increased *T. harzianum* root colonization and abundance of AMF, as well as improving overall productivity in Arabidopsis and rapeseed plants (Poveda, 2019). T-22 is a widely-used hybrid strain of *T. harzianum* developed by Gary Harman and colleagues at Cornell University in the mid-1980's. This strain has the ability to colonize most plant root systems effectively across a wide variety of soil types (Harman et al., 2004). Application of T-22 to *Prunus* genus plants during the rooting phase resulted in "greater shoot lengths, increased number of leaves, roots and stem diameters." These benefits increase the likelihood that nursery planted material will be of high quality and viability will be retained after the acclimation phase (Sofo, 2010). Mature plants also reap the benefits of T-22 inoculation. Corn plants whose roots are colonized by T-22 strains require around 40% less nitrogen fertilizer than control plants without T-22 application (Harman, 2000), demonstrating that they can aide plants beyond biocontrol activities.

The universal adoption of microbial inoculants like T-22 face many obstacles. For example, while inoculants like T-22 are highly successful in promoting plant health under controlled settings, they can be much less effective, or completely ineffective, in field settings (Nicot et al., 2011; Nieto-Jacobo et al., 2017). One of the reasons for this inconsistency could be due to crop genotype or variety. The developer of the T-22 stain, Gary Harman, wrote in 2006 that "… at least in maize, the increased growth response is genotype specific, and some maize inbreds respond negatively to some strains." (Harman, 2006) Similar results were reported in tomato with respect to ISR against foliar pathogens (Tucci et al., 2010). Tucci et al., 2010 later concluded that "in the case of strains such as *T. harzianum* T-22, one of the most widely used biopesticides, there is still a substantial lack of knowledge on how the expected beneficial effects of *Trichoderma* application depend on the treated plant genotype." Subsequent research from Purdue University's Horticulture department confirmed that tomato genotypes vary in their ISR responses to T-22 application, and genetic responsiveness to *Trichoderma* appears to have been lost over the course of crop domestication (Jaiswal et al., under review). Investigation into the genetic mechanisms underlying these differential responses among tomato genotypes in underway. In the meantime, studies documenting the extent to which tomato genotype or variety can indeed influence the efficacy of T-22 in field settings are needed. Other factors that could influence the efficacy of microbial inoculants like T-22 in field setting are soil quality and availability of labile pools of SOM to help support the fungus in its saprophytic phase.

T. harzianum, and other soil fungi, are just one portion of the microbiome found in soils. A healthy soil microbiome is extremely diverse and composed of billions of bacteria, fungi, protozoa, viruses and archaea from thousands of taxa (Fierer, 2016). The composition of microbes in a soil depends heavily on abiotic (i.e. nutrient levels, pH, nutrient levels, climate) factors, biotic (i.e. plant type) factors (Fierer and Jackson, 2006; Penton et al., 2014; Fierer, 2016) and soil management practices such as tillage. Fungi are vitally crucial to the maintenance of a healthy, functional soil. While bacteria make up the largest portion of a soil's microbiome by number, fungi make up the largest portion of soil biomass in undisturbed soils (Hoorman and Islam, 2010). Fungi are especially susceptible to depletion from cultivation as their hyphae are large enough to be torn apart, thus destroying mycelium (Reid et al., 2013). Since most soil fungi are primarily saprophytes, they are also dependent on the availability of fresh supplies of decomposable organic materials.

Amending soils with fresh organic matter is critical to maintaining the health and productivity of soils in agricultural systems. Fresh supplies of SOM are critical for supporting soil macro- and microfauna that provide critical agroecosystem services. These fresh supplies of organic materials can also provide nutrients for plants following decomposition by the soil microbial communities. The carbon (C) and nitrogen (N) ratio of these organic materials is an important consideration as this can affect the rate at which microbes are able to decompose these materials and release nutrients for plant uptake. For example, C:N ratios between 1 and 15 release nutrients like nitrogen relatively quickly, though this can also lead to N loss via leaching and/or evolution of nitrous oxide gas if N supplies are not linked with critical periods of N uptake (Hoagland et al., 2008; Rudisill et al., 2015). Ratios between 20 and 30 represent an equilibrium state between mineralization and immobilization. Immobilization is a state in which nutrients like N are taken up in their mineral form by microorganisms and therefore become unavailable to plants. Tying up nutrients like N in this manner can lead to severe crop nutrient deficiencies. Immobilization dominates at C;N ratios above 35 (Brust, 2019). For this reason, the USDA's Natural Resources Conservation Service (NRCS) recommends feeding the soil with organic materials containing a C:N ratio of around 24:1. Alfalfa hay's ratio of 25:1 makes it an ideal amendment (USDA NRCS, 2011). Excess application of organic materials with higher C:N ratios hinder mineralization and suppress plant growth and productivity (Mahal et al, 2019).

The C:N ratio of fungal organisms averages between 7:1 and 25:1 due to the chitin and melanin chemical composition of their cell walls (Scow, 1997). In contrast, bacterial cell walls are made of peptidoglycan phospholipids and are comparably more energy-rich., resulting in lower C:N ratios, averaging around 5:1-7:1. Therefore, soil fungi require less C relative to N than bacteria, and fungi are better equipped to decompose organic materials that have high C:N ratios due to their ability to secrete complex enzymes. Also, soil fungi are more tolerant of acidic conditions compared to bacteria, which can be influenced by the C:N ratio of organic materials (Hogberg et al., 2006).

Amending soils with compost is one way to supply fresh organic materials and support the health of soil and the microbes that thrive within soils and plants. Composting is the process of "creating humuslike organic materials by aerobic decomposition outside the soil (Brayd & Weil, 2010). Deciduous leaves are a popular composted material in urban environments as they are available on the lawns of many households during autumn months in the United States. Municipalities also collect leaves from trees in city parks and ornamental trees interspersed throughout the city, such as along roadsides. Trees planted in urban settings provide many more benefits to the local community than simply aesthetic beauty. They reduce carbon emissions, regulate water flow and can filter urban pollutants. In addition, they can provide fruits, nuts and leaves to the local community (FAO, 2016). Fallen leaves are an especially important by-product of tree planting because they make up the largest amount of compostable organic material in urban settings. In fact, the *Rodale Book of Composting* notes that "the leaves of most trees contain twice the mineral content of manure" (Gershuny and Martin, 2018). The deep, extensive root system of trees use capillary action to transfer minerals deep within the soil to the leaves (Greater Victoria Compost Education Centre, n.d.). While leaf compost may contain smaller quantities of nutrients compared to conventional fertilizers, it contains many growth-promoting enzymes and hormones that commercial fertilizers do not (Naikwade, 2014).

Brown organic wastes, like dead leaves, act as bulking agents and are the preferred compostable material of fungi due to their high C:N content. Most compost recipes call for nitrogen-rich green organic wastes, like grass clippings, to be added to the carbon-rich brown organic material to create a more balanced compost. Nitrogen-rich organic wastes decrease the C:N ratio considerably, providing energy for bacterial decomposers, which results in a finished compost that will have a lower C:N ratio. However, farmers and gardeners alike can choose to leave out the nitrogen-rich greens and produce a compost with a higher C:N ratio (Travis, 2017). The average C:N ratio of compostable leaves is 60:1. Leaves in the early stage of decomposition are also quite acidic, with pH levels at or below 6, depending on the tree (Cornelissen et al., 2010). Farmers and gardeners can develop a further specialized material known as 'leaf mold compost' by forgoing the turning process meant to increase aeration and heat during traditional composting processes. In this case, organic materials are decomposed more slowly, using a cooler fungal-driven process resulting in a material with a higher fungal to bacterial ratio. Composts with higher fungal to bacterial ratios are expected to impart greater biocontrol activities against pathogens (Bonanomi et al., 2018). In addition, by forgoing the addition of "greens", as well as animal wastes that are commonly included as a feedstock during compost generation, composts with lower ratios of phosphorus (P) relative to N can also be generated. When farmers rely exclusively on organic amendments like compost to supply nutrients, particularly N, soils can become enriched in P, which can negatively interfere with plant uptake of other critical nutrients like calcium and lead to water quality problems, such as eutrophication (Rudisill et al., 2016).

Compost provides many benefits to the soil but arguably the most important is its ability to replenish SOM which, as a reminder, is "the fraction of the soil that consists of plant or animal tissue in various states of breakdown" (Cornell Soil Organic Matter, n.d.). OM is made up of three parts: 1) plant residues and living microbial biomass, 2) detritus, or active soil organic matter and 3) humus, which is stable decomposed plant and animal tissue (Cornell Soil Organic Matter, n.d.). The first and second components of SOM can contribute to a plant's fertility needs. On average, for every 1% increase in OM, 10-40 lb N, 4-7 lb P and 2-3 lb S are released by the soil each summer and are therefore available for plant uptake (Brady & Weil, 2009; University of Massachusetts Extension, n.d). The third fraction is stable and have been thoroughly processed by soil microbes. This fraction contributes to the soils' cation exchange capacity (CEC), and therefore directly affects the soils' ability to retain nutrients. All fractions are critical for maintaining aggregate stability and soil tilth, which creates pores for water, air and root movement. Once soils are cultivated, SOM pools are depleted over time and must be replenished to maintain the health of soils and productivity of agricultural systems. However, conventional farming methods rarely maintain the recommended OM level of 3-6% (USDA NRCS, n.d. a). With their high C:N ratio and high organic matter content, leaf mold composts could help reverse the trend.

Another benefit of the leaf mold compost is its capacity to retain 300-500% of their weight in water, thus reducing irrigation needs in agricultural systems (Gershuny and Martin, 2018). Rich, healthy topsoil is only able to hold 60% of its weight in water. Marais et al. (2012) said that, "statistical analyses showed that soil moisture had an over-riding effect on seasonal fluctuations in soil physicochemical and microbial populations." Leaf composted plots also show improvements in overall crop yield (Naikwade, 2014) and less year-to-year variation in yields (Maynard and Hill, 2000). Leaf mold composts add much needed aggregation to the structure of the soil. Well-aggregated soil provides housing options for microbes. Leaf compost's high C:N ratio and ability to increase soil aggregation are also expected to promote the growth of microbial antagonists in soil, such as *Trichoderma harzianum* (Abdel-Kader et al., 2013; Maynard, A. A., &; Hill, D. E., 2000). Urban agriculture operations, and fungal communities, can benefit tremendously from composting these fallen leaves and utilizing them on their operations.

3.2 Methodology

3.2.1 Research Justification and Objectives

Interest in urban agriculture is growing rapidly due to its potential to help address food insecurity, restore blighted neighborhood and connect communities, among other benefits. Soils in urban systems are often severely degraded, however, and they can be contaminated by heavy metals due to local industries, past use of leaded gasoline and lead paint. Most urban growers prefer to use organic production practices due to concerns over the negative health impacts of pesticides, as well as logistical challenges associated with using pesticides in the city. As a result, vegetable growers often struggle to manage pests. Tomatoes are one of the most popular crops grown in urban agricultural systems in the Midwest U.S. In a recent survey, organic tomato growers reported that diseases caused by pathogens were their greatest production challenge (Hoagland et al., 2015).

The primary goal of this study was to determine if amending a degraded urban soil with leaf mold compost could improve soil health and increase the productivity and potential for tomato plants to withstand disease pressure. Next, we aimed to determine whether inoculating tomato transplants with *T. harzianum* T-22 could help the tomato plants withstand abiotic stress imposed after transplanting in the field. Third, we aimed to determine if the presence of a leaf mold compost provided better support for the survival and potential of the T-22 community as it enhanced tomato plant growth and helped the plants fight pathogens that cause disease. Finally, we wanted to test the hypothesis that the survival and efficacy of T-22 inoculants in the field can be influenced by tomato genotype.

3.2.2 Field Site

This study was conducted at Purdue University's Student Farm which is located on the northernmost side of campus in West Lafayette, Indiana, and surrounding by golf courses and residential neighborhoods. Soils at this site are classified as part of the Starks-Fincastle Complex, which typically have poor drainage and high concentrations of SOM (NRCS, Web Soil Survey). The land was privately farmed prior to being purchased by Purdue during 2016. The previous owner grew corn and soybean crops by way of conventional farming methods, including frequent tillage for many years. The student farm was established during 2016-17. During establishment, drainage tiles were installed to facilitate better drainage and the soils were further disturbed during construction of roads and other infrastructure at the farm.

The field trial described here was initially conducted during summer 2019 and repeated during summer 2020 on adjacent plots of land located in the northeastern part of the farm (see Figure 3.6). These plots have been managed by the Hoagland Lab using certified organic practices since 2017, which has included incorporation of winter and summer crops to help restore soil health in these plots. The location for the 2019 field trial is highlighted in red while the 2020 field trial is highlighted in yellow. Both plots had previously been planted with a winter cover crop mixture using untreated seed of winter rye, field peas, ryegrass, crimson clover, and hairy vetch that was mowed and disked into the soil approximately four weeks before establishment of the field trials described below. During the previous summer crop season, each plot had been planted with a summer cover crop of sorghum-sudangrass, and the year prior, a mixture of carrot genotypes. Laboratory tests were conducted in the Hoagland lab of the Horticulture building located at 625 Agriculture Mall Dr., West Lafayette, IN 47907.

Figure CHAPTER 3.6. Google Maps image of the 2019 & 2020 field plots

3.2.3 Experimental Design

The field trial was established as a split-plot design with three levels (see figure 3.7). First, the entire 36’ x 110’ plot area was divided into large, 10’ X 18’ plots representing compost or control (no soil amendment) treatments established in a randomized block design with four replications to help minimize the effects of variability within the larger plot area. Next, each of these larger plots was split, with one row of tomato plants receiving the T-22 inoculant and the other half treated with a sterile water control. Finally, within each row, two commercial varieties of tomatoes were planted: Corbarino and Wisconsin 55, each with 6 plants.

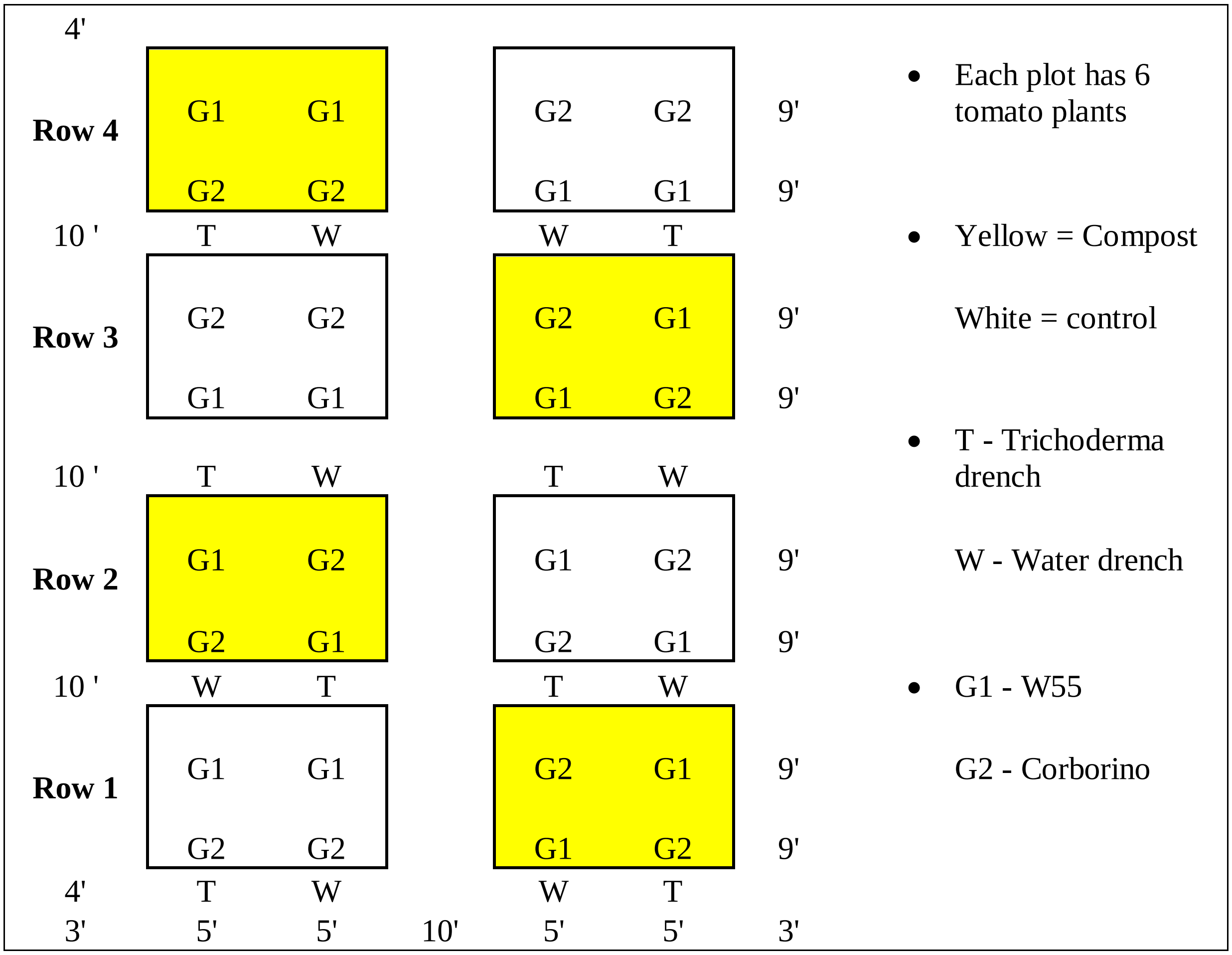


Figure CHAPTER 3.7. Overhead schematic of tomato field trial

Figure CHAPTER 3.8. Looking west with row 1 closest to the camera

Table CHAPTER 3.1. Experimental treatment groups

Variety	Inoculation	Compost
1. Wisconsin 55	No	No
2. Wisconsin 55	No	Yes
3. Wisconsin 55	Yes	No
4. Wisconsin 55	Yes	Yes
5. Corbarino	No	No
6. Corbarino	No	Yes
7. Corbarino	Yes	No
8. Corbarino	Yes	Yes

3.2.4 Leaf Mold Compost

The leaf mold compost was produced by local farmer Dan Perkins of Perkins' Good Earth Farm in Jasper County Indiana (https://perkinsgoodearthfarm.com/). Mr. Perkins receives 80-90 dump truck loads of municipal leaves from the nearby town of Demotte, Indiana. These shipments are dumped in windrows at Mr. Perkins farm. 90% of these shipments are leaves, with the remaining 10% being grass clippings. A cold composting process is utilized to ensure that the process is driven by primarily fungal species. Leaves are left alone most of the year but are turned once or twice within the windrows using a backhoe to help keep the process moving. The leaf compost is tarped for weeks during mid-summer to kill any weeds that may be growing and to ensure that weed seeds do not incorporate into the compost by way of wind or animal activity. Below is the finished product.

Figure CHAPTER 3.9. Three year old leaf compost

Leaf compost from Mr. Perkins' farm was delivered to the Purdue University student farm each spring for use in the field trial. A representative subsample of the leaf mold compost was collected each spring and sent to Midwest Labs in Omaha, NE (https://midwestlabs.com/) for a compost analysis conducted using standard laboratory practices (see Tables 3.2 and 3.3). The compost was also sent to a soil test lab at Loyola University in Chicago, IL (https://www.luc.edu/healthyhomes/toxins/leadheavymetals/) during 2019 and to Midwest Labs in 2020 to test for the presence of heavy metal contaminants since this could be a potential issue with composts developed using urban waste streams (see Table 3.4). In fact, inorganic contaminants such as heavy metals are not destroyed by the composting process (Brady and Weil, 2009). Results indicated that the composts did not contain any heavy metals at levels that would be considered unsafe for plants or humans by the EPA or New York State Department of Environmental Conservation standards (see table 3.4).

Table CHAPTER 3.2. Midwest Laboratories compost nutrient analyses for 2019 and 2020 (lb per ton)

Year	Organic N	Nitrate N	P	K	S	Ca	Mg	Fe	Mn
2019	17.8	0.6	2.2	3.0	2.0	27.6	5.0	4.6	0.3
2020	17.2	0.4	2.4	4.4	2.6	42.2	8.4	3.0	0.3

Table CHAPTER 3.3. Midwest Laboratory compost properties analyses for 2019 and 2020 (lb per ton)

Year	C:N ratio	pH	Chloride	Organic Matter
2019	13:1	7.0	< 0.01	758.0
2020	13:1	6.9	< 0.01	458.0

Table CHAPTER 3.4. Heavy metal test results from Loyola University (2019) & Midwest laboratories (2020)

Year	As	Cd	Cr	Cu	Ni	Pb	Zn
2019	1.36	0.22	1.92	10.91	1.21	1.26	33.3
2020	n.d.	n.d.	4.24	11.8	2.5	5.4	68.4
EPA Standard	N/A	< 78	< 230	< 2900	< 1600	< 400	< 23000

3.2.5 Preparation of *Trichoderma harzianum* T-22 inoculant

The initial *Trichoderma harzianum* T-22 fungal isolate was obtained from Bioworks, Inc., a company founded by Dr. Gary Harman at Cornell University, and is kept in the Hoagland

Research Lab in the Department of Horticulture and Landscape Architecture at -80C until needed for research purposes. Petri plates containing potato dextrose agar (PDA) were prepared to facilitate *T. harzianum* growth in the laboratory. The recipe includes: 39 g PDA and 0.25 g of the antibiotic chloramphenicol for every 1L of distilled water. This solution is autoclaved to ensure that microbial growth does not contaminate the solution. Over the span of a few minutes, this solution begins to gel and harden at room temperature. Microwaving the gelatinous mass for 6 minutes in a standard microwave melts the solution into a liquid solution once again. At this point, roughly ½ in. layers of the solution are poured into standard plastic agar plates. Agar plugs of the *T. harzianum* isolate frozen in glycerol stock and stored in the -80ºC freezer were placed in the center of the agar plates once the growing medium has solidified and dried. The fungus was then allowed to grow for five days whereby fungal growths begin to congregate near the edge of the plate. At the five-day mark, more PDA was heated and poured into plates. A 15 mm cork-borer was then used to punch holes into the five-day old agar plates, and these plugs were placed in the center of fresh PDA plates. These plates were then placed in a plastic container at ambient conditions where they were allowed to mature for 10-12 days. During this maturation time, the fungal mycelia spread and begins to produce conidia (asexual spores). Once matured, 20ml of distilled water was added to each agar plate to gently scrape off the fungal conidia into a solution. The solution was poured into a 1L laboratory flask that was covered with cheese cloth folded over three times to permit passing of conidial spores and remove hyphal fragments. The final solution inside of the flask should contain two parts distilled water for every part of *T. harzianum* conidial spore suspension in the infused distilled water. For example, if ten agar plates were cleaned using 20ml distilled water per plate, the flask should contain 200ml of a distilled water and *Trichoderma harzianum* conidial spore solution. 400 mL of clean distilled water should then be added to the 200ml solution to dilute the sample. Finally, subsamples of this solution are viewed under the microscope and the concentration of conidia in the solution is determined using a hemocytometer. The solution is then diluted to a final concentration of 10^7 conidial spores per ml distilled water, and inoculated onto the base of tomato plants as a ”*Trichoderma* drench”.

3.2.6 Tomato Growth Schedule

Untreated tomato seeds of the varieties Corbarino and Wisconsin 55 were sewn into one of four 72 cell trays filled with Berger® BM2 potting mix. Two trays were planted with Corbarino variety tomatoes, while the other two trays were planted with Wisconsin 55. These trays were placed in the Horticulture department's propagation room within in its greenhouse and were allowed to germinate and establish for 1-2 weeks. Trays were then placed in the greenhouse bay assigned to the Hoagland lab. Tomato plants were fertigated once a day or as needed to prevent oversaturation. Seedlings were thinned to ensure that only one tomato plant per cell grew. At this point, one tray containing each variety received a 1ml *T. harzianum* drench around the base of the emerged plant, while the remaining two trays received a sterile water control treatment. The four trays of tomato plants were removed from the greenhouse and placed outdoors in the shade to acclimate to the outdoor environment prior to transplanting in the field. The treatment group received a 20 ml fungal drench the day they were planted in the field and a final 20 mL around 50 days after the previous inoculation. Table 3.5 reports important dates for the growth schedules of 2019 and 2020.

Table CHAPTER 3.5. Important tomato growth dates

Event	**2019**	**2020**
Sewing	April 23rd	April 16th
Tomato plants moved from propagation room to regular greenhouse room	May 1st	April 30th
Received 1st fungal inoculation (1mL)	May 16th	May 2nd
Tomato plants moved from greenhouse to acclimate outdoors	June 14th	May 23rd
Tomato plants planted into the ground	June 18th	June 3rd
Received 2nd fungal inoculation (20mL)	June 18th	June 3rd
Received 3rd fungal inoculation (20mL)	July 30th	July 25th

3.2.7 Field Trial Establishment and Management

Prior to leaf compost incorporation, the research plot was tilled and Re-Vita Pro™ 5-4-5 granular heat-treated chicken manure was applied to the field as a fertilizer. The rate targeted for the fertilizer application was 185 lbs of total product per acre. This rate was developed considering that nutrient needs of the tomato crop and the expectation that additional nutrients would be derived from the leguminous cover crop planted the previous winter, and residual contributions from organic fertilizers applied during previous years. Since the release of nutrients from stable composts is generally quite low (average of 10-20% during the application year), the leaf mold compost used in this study was only expected to supply limited nutrients to the tomato crop.

After the plots had been fertilized, a 3 in. layer of leaf compost was applied to the four large compost sections. The composts were incorporated using a walk-behind rototiller in 2019 (BCS) and a tractor with a roto tiller attachment in 2020. After rototilling, four rows of raised beds with drip tape irrigation line covered in black biodegradable plastic were created using a Rain-Flo Raised Bed Plastic Mulch Mini Layer implement. Finally, untreated cover crop seed (Dutch white clover and annual rye) was planted by hand in between the subplots, and between the plot rows to stabilize and protect soils in the walkways between tomato rows and the non-plot areas.

Tomato plants were irrigated utilizing drip tape as needed to ensure that the soil did not become too dry. There was no set irrigation schedule. Pesticides of any sort were not used to control insects in the plots. However, tomato plants were visually inspected for devastating damage from the tomato hornworm, *Manduca quinquemaculata*. This pest commonly attacks plants of the Solanaceae family, of which tomatoes are members. Damage from tomato hornworm was minor in 2019 and virtually non-existent during the 2020 season. One mature tomato hornworm was captured and removed from a tomato plant during the 2019 season and none were removed during the 2020 season.

Tomato plants were allowed to run roughshod as they were not pruned during the growing season. Pruning is a well-known method to reduce disease incidence, particularly early blight. One objective of this experiment was to discover the differences in disease suppression in the different treatment groups. Disease-causing pathogens were allowed better contact with plants because of our decision not to prune. This was done so that differences in disease incidence had the opportunity to be more pronounced and to reduce the variables responsible for variations in disease severity. No pesticides were applied to control diseases either.

3.2.8 Soil Testing

Eight random soil cores were collected to a depth of 6” using a 10-cm soil probe in each large plot area prior to establishment of the field trials in each year. Individual soil cores from each large plot were pooled, brought back to the lab on ice and air-dried. The soil samples were sent to Midwest Labs for a standard soil test to obtain baseline information of chemical properties for each trial. The standard soil tested included assessment of the total soil organic matter (%), P_1 (Weak Bray), P_2 (Strong Bray), Potassium (K), Magnesium (Mg), Calcium (Ca), pH and cation exchange capacity using standard practices. P_1 (Weak Bray) values indicate approximately how much phosphorous is available in the soil and P_2 (Strong Bray) values indicate total soil phosphorous (see Table 3.7). During 2019, soils from both plot sites were sent to Loyola University for heavy metal testing and results indicated that the plots did not contain heavy metals at levels considered unsafe for plants or people. Heavy metal testing in soils is recommended about as often as they are usually tested for fertility, which is generally around once every three years (Johns Hopkins Center for a Livable Future, n.d.), so the test was not repeated in 2020.

Approximately 19 days after the field trials were established, 10 random soil cores were collected within each of the larger compost or no amendment control treatments, pooled and brought to the laboratory on ice for several soil health assays described below. Subsamples for biological analyses were held at 4C until analysis and some of the soil was air-dried prior to processing depending on the assay performed.

Fluorescein diacetate (FDA) hydrolytic assay

The soil microbiome is an ever-increasing topic of research as scientists begin to understand the effects of a thriving microbial ecosystem as it pertains to plant growth and fruit production. Quantifying the activity of microbes in the soil is of particular interest as this provides a general measure of organic matter turnover in natural habitats. Nearly 90% of the energy in the soil environment passes through microbial decomposers (Heal and Mclean, 1975). Soil microbial activity can also be an important indicator for the potential disease suppressive activity of soils. One method to quantify soil microbial activity is the fluorescein diacetate enzyme assay (Green et al., 2006). Fluorescein diacetate [3’,6’-diacetylfluorescein (FDA)] is a colorless compound that is added to soil before being hydrolyzed, or broken down, by various microbial enzymes (Brunius, 1980; Lundgren, 1981; Schnürer and Rosswall, 1982). These include proteases, lipases and esterases. The reaction equation is:

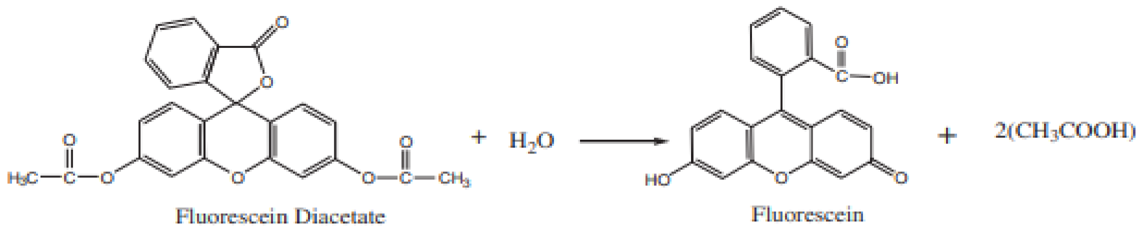


Figure CHAPTER 3.10. FDA reaction equation (Green et al., 2015)

As seen from figure 3.10, fluorescein is the product of the enzymatic reaction. Thus, fluorescein abundance gives an estimate of the total microbial activity of a soil's microbiome. Fluorescein is a fluorescent yellow-green compound and can be measured by spectrophotometry (Swisher and Carrol, 1980, Schnürer and Rosswall, 1982).

The protocol for this assay was developed by Green et al. (2006) from Purdue University's Department of Agronomy. Reagents for the FDA hydrolysis assay include: acetone, a 60 mM sodium phosphate buffer, 4.5 mM FDA stock solution and fluorescein standard stock solution. To conduct the assay, 1g samples of air-dried soil is sieved through a 2mm sieve before being placed in a 125 mL Erlenmeyer flask. The assays was performed in triplicate for each soil sample, along with one soil blank and one reagent blank with no soil giving 33 flasks in total. 50 mL of the 60 mM sodium phosphate buffer and 0.50 mL of the 4.8 mM FDA stock solution were added to the soil in the 125 mL Erlenmeyer flask. The solution was swirled for a few seconds and incubated at 37ºC for three hours. 2 mL of acetone was added to terminate the hydrolysis of FDA once the three-hour period is complete. 30 mL of this solution was added to a 50 mL centrifuge tube and centrifuged at 4700 RPM for 5 min. The supernatant was filtered through Whatman No. 2 filter paper. Fluorescein standards of 30, 100, 300, and 500 µL were used to generate a calibration curve. All reactions were quantified using a microplate spectrophotometer (BioTek) at 490 nm. The calibration curve gives a linear regression equation in the form y=mx+b. The y-axis of the soil samples is the following equation:

- $y=OD_{490}$ (soil samples) - OD_{490} (soil blank) - OD490 (reagent blank)

This y value was plugged into the calibration curves linear regression equation. "x" is the only unsolved variable in the equation and represents the mg of fluorescein per gram of dry soil. Plug the value of y into the equation, and you are given the value of x which is mg of fluorescein/g dry soil.

Soil permanganate oxidizable carbon (POXC) quantification

Carbon (C) levels in a soil sample provide a useful estimation of SOM as C is the primary element that makes up organic matter. Quantifying “labile” or “active” soil carbon is necessary to capture the biologically active C fraction of SOM. Labile or active soil carbon is the mineralizable element that is associated with short-term fertility (Calderon et al., 2017). In other words, this is the portion of organic matter actively involved in the process of nutrient cycling in the soil. Cycling allows nutrients to become available to growing crops. Labile or active soil carbon is also the fraction of SOM that supports the diversity and activity of soil microbes that perform diverse functions from nutrient cycling to disease suppressive activity. Finally, while total SOM is very slow to change, and therefore is generally not useful in quantifying the effects of management practices on soil health, active or labile fractions change more quickly and therefore serve as a better indicator. Permanganate oxidizable carbon (POXC) is a commonly used method to measure active C in a soil sample.

The protocol for the POXC soil assay was developed by Weil et al., (2003). Three reagents are needed to complete this test: reagent grade potassium permanganate, reagent grade calcium chloride, dehydrate and a pulverized, homogenized soil standard used as a laboratory reference. A 0.2 M $KMnO_4$ stock solution is also prepared. The laboratory assay was performed in triplicate, along with a triplicate of the soil standard and a reagent blank. 2.5 g of air-dried soil was placed into 50 mL centrifuge tubes. 18 mL of deionized water was added to each tube, along with 2 mL of 0.2 M $KMnO_4$ stock solution. Samples were placed on a shaker for two minutes at a speed of 120 rpm where they were then removed and placed in a dark setting for ten minutes while the reaction occurred. 0.5 mL supernatant is pipetted into 49.5 mL of deionized water. These were the final sample solutions for analysis. Standard stock solutions of $KMnO_4$ at concentrations 0.005, 0.010, 0.015 and 0.020 M were prepared to create a standard curve. Absorbance levels were measured by spectrophotometry on a Biotek spectrophotometer at 550 nm. The following equation was used to determine POXC levels:

- POXC (mg kg^{-1} soil) = [0.02 mol/ L - (a + b × Abs)] × (9000 mg C/ mol) × (0.02 L solution/ Wt)
- a = intercept of the standard curve, b = slope of the standard curve.

The amount of carbon oxidized is a function of the quantity of permanganate reduced. This means that increased POXC values corresponds to lower absorbance levels.

Inorganic soil nitrogen tests

Nitrogen (N) is widely considered the most limiting and therefore critical element for plant growth and productivity. The N cycle is the route that N flows into and out of the soil system. N exists in the soil in many different forms within the N cycle. These forms can interchange quite easily from one another. Biological processes, climatic conditions and anthropogenic activity all affect the N cycle, though specialized soil microbes are the main driver. N sources must be converted into the inorganic forms of ammonium (NH_4+) or nitrate (NO_3-) before they are considered available for uptake by plants (University of Minnesota Extension, n.d.). Plant residue, especially from legumes, contains complex organic forms of N that must mineralize into inorganic forms before they are available for plant uptake and use. SOM is another major source of N taken up by crops. For each percent of organic matter, approximately one ton of N in organic forms exists. The release of inorganic N is quite slow and each percent of organic matter releases around 20 pounds of available N $acre^{-1}$ $year^{-1}$. Quantifying inorganic N levels in a soil is important for estimating nitrogen fertilizer application rates and, when analyzed in conjunction with SOM percentages, can give an indication of a soil microbiome's mineralization efficiency.

Inorganic N species in the soils were quantified using KCl extractions in duplicate. Soils were separated through a 2 mm sieve and 5 g of each sample were place into a 50 mL tube. 12.5 ml of 1M KCl was added to each tube. The tubes were shaken vigorously and then placed horizontally in a shaker at 250-300 rpm for 30 minutes. This solution was shaken vigorously again and immediately filtered through Whatman No. 2 paper and the supernatant was placed into 15 mL centrifuge tubes. These samples were taken to the lab of Niki de Armond in the Lilly Hall of Life Sciences located at 915 West State Street, West Lafayette, IN 47907. At this stage, research technician de Armond quantified the amount of nitrate, nitrite and ammonia for each sample by running the samples on a SEAL discrete analyzer (https://www.seal-analytical.com/Home/tabid/127/language/en-US/Default.aspx) which quantified these compounds based on their potential to fluoresce at certain wavelengths.

3.2.9 Survival of the T-22 microbial inoculant

Approximately 11 days after the final *T. harzianum* inoculation was administered to treatment plants, soil samples were collected to a depth of 0-20 cm using a 10 cm diameter probe at the base of tomato plants within each individual tomato X inoculant X soil amendment treatment (32 samples total). The goal was to obtain soil as close to the roots as possible so this could conceivably represent the rhizosphere (area immediately adjacent to and influenced by the root), without harming the roots. Four cores were taken within each plot containing 6 tomato plants, and the individual cores were pooled in each sample and transferred to the lab on ice where they were stored at 4°C until analysis.

Polymerase chain reaction (PCR)

Polymerase chain reaction (PCR) is a technique used to amplify target segments of DNA. Analyzing pieces of DNA requires enormous amounts of product so fragments must be amplified using PCR. In this case, PCR was conducted to determine whether T. harzianum species were present in the rhizosphere of all 32 treatment samples, random treatment samples, solely inoculated samples or no samples. To conduct PCR assays, DNA was extracted from each soil sample in duplicate using a DNeasy PowerSoil Extraction Kit (Qiagen) following the manufacturer's instructions. Briefly, 0.5 g soil samples were placed in a 2ml tube with an extractant and beads, placed in a tissue homogenizer to lyze microbe cells, and then subject to multiple filter steps to clean and concentration the DNA. The quality and quantity of the DNA was determined using a NanoDrop spectrotometer and samples were diluted to a consistent concentration (10 ng/ml) before being stored at -20°C before analysis. DNA extracted from soil samples was prepped for PCR by pipetting the DNA and other reactions into PCR-specific Eppendorf tubes. The reaction mixture for each PCR reaction is depicted below (see Table 3.6). PCR reactions were conducted using a Biorad T100 Thermocycler.

Table CHAPTER 3.6. Reaction mixture for polymerase chain reaction (PCR)

Ingredient	Amount (µL)
Master Mix®	12.5
Forward Primer (10 µM)	1.25
Reverse Primer (10 µM)	1.25
DNA (10 ng/µL)	1.5
Nuclease Free Water	8.5
Total	25

Once the reaction mixture finished in the thermal cycler, samples were loaded into electrophoresis gel wells. Gels are formed by the mixture of 100 mL TAE buffer, and 1.5 g agarose, microwaving for 1.5 min. and 10 µL R2 stain. A mixture of 1 µL of comassie blue dye and 3 µL of the post-PCR mixture were loaded into individual PCR wells. Gel electrophoresis was allowed to run for 30 min. at a level of 100 V. Afterward, gels were analyzed using UV light imaging to observe which samples contained *T. harzianum* organisms and which did not.

Quantitative polymerase chain reaction (qPCR)

Real time PCR, or quantitative PCR (qPCR), is a modern method for quantification, detection and typing of different microbial DNA (Kralik and Ricchi, 2017). qPCR is called real time PCR because it allows measurements to be taken after each cycle to calculate the momentary quantity of amplification based on fluorescence signal detection. Early cycles do not detect DNA as the quantity is below the threshold for detectability. The cycle at which fluorescence intensity is detectable corresponds proportionally to the initial number of template DNA molecules in the sample (Kralik and Ricchi, 2017). In other words, qPCR was utilized to quantify the amount of *T. harzianum* DNA in each of the 32 treatment samples to identify whether inoculation treatments, compost treatments and/or tomato genotype significantly affected *T. harzianum* survival and abundance rates. Below is the qPCR reaction mixture (Table 3.7).

Table CHAPTER 3.7. Reaction mixture for quantitative polymerase chain reaction (qPCR)

Ingredient	Amount (µL)
SYBR Green Master Mix®	7.5
Forward Primer	0.2
Reverse Primer	0.2
DNA	4
Nuclease Free Water	3.1
Total	15

Plate counts to quantify T-22

Soil samples were plated onto selective media for *Trichoderma* in petri plates. All ingredients except Captan were mixed with DI water and autoclaved. While autoclaving, a stock solution containing 0.2g Captan in 10 mL autoclaved water was made. 1 mL of this stock solution is added for every L of selective media after autoclaving. Below is the recipe for the *Trichoderma* media (Table 3.8).

Table CHAPTER 3.8. Reaction mixture for *Trichoderma* selective media (TSM)

Ingredient	Amount (g/L)
Magnesium Sulfate	0.2
Dibasic Dipotassium Phosphate	0.9
Potassium Chloride	0.15
Ammonium Nitrate	1.0
Glucose	3.0
Chloramphenicol	0.25
Rose Bengal	0.15
Agar	20
100% Dexon	0.18
Pentachloronitrobenzene	0.16
50% Captan	0.02

The assays were conducted in triplicate for each soil sample. Prior to plating the soils, they needed to be rehydrated in order to activate *T. harzianum* again as they were dried and had been in a 4ºC cooler. 5 g of soil was placed in a 50 mL Falcon tube with 1.25 amount of water and incubated at 25ºC for 48 hours. Once this was accomplished, a 0.1% water agar (WA) was created by adding 1 g agar to 1 L of autoclaved water. 2.5 g of soil was added to 22.5 ml 0.1% WA and shaken at 150 RPM and 25ºC for one hour horizontally. This 25 ml solution is the “initial solution”.

The moisture content of the remaining 2.5 g of soil was calculated to accurately measure *T. harzianum* presence. Moisture content was found by subtracting the weight of the dry soil from the weight of the wet soil and dividing this result by the dry weight. Finally, dilutions were created of magnitude 10^{-1}. The 10^{-1} dilution was accomplished by adding 100 µL of the original solution to 900 µL of 0.1% WA. 100 µL of this dilution was spread well on the selective media and allowed to dry for 1-2 hours. Once dry, each plate was covered and placed in a plastic container where it was allowed to grow. After 7 days, the number of *Trichoderma* colony forming units (CFUs) were counted on each plate.

CFU's were utilized in order to calculate the population of *Trichoderma* organisms in one gram of dried soil for each sample. This was done using the following equation:

- CFU / (suspension volume per plate * (1/dilution factor) * (weight of dried soil / initial solution volume)

Once this was done, samples were grouped into their four treatment groups and an average was taken for each treatment.

3.2.10 Analytical tests and observations of tomato health and productivity

Survival following transplanting

When tomato seedlings are transplanted from flats into the field they are subject to many stress factors including wind, heat, water and soil-borne pathogens. The healthier these seedlings are, the better they will be able to survive this transplant stress and go on to develop into mature and productive plants. The number of seedlings that survived or died following transplanting was recorded within one week after transplanting in each year. Dead seedlings were replaced until supplies were exhausted in each year.

Spad readings

Nitrogen (N) levels are extremely important to estimate because N is the major component of chlorophyll, which is the main compound plants utilize to create sugars from sunlight and water. N deficiency symptoms include poor plant growth and pale green or yellow leaves due to this inability to make sufficient amounts of chlorophyll. Affected areas (or the entire plant) may be stunted or fail to produce flowers and fruit. In addition, chlorotic leaves are more prone to scorching and leaf diseases (University of Illinois Extension, n.d.). The relative chlorophyll content in leaves can be estimated by utilizing the SPAD 502 chlorophyll meter. This is an efficient way to evaluate plant N status in many crops and some tree species (Bonneville, 2006). The SPAD 502 meter can spot N deficiencies long before the human eye detects changes to the "greenness" of the plant. This method is quite useful as it can be taken non-invasively while the leaf is still attached to the vine. Tomato leaves were clamped inside of the meter and an indexed chlorophyll content score was shown in less than 2 seconds. These indexed scores were recorded and transferred to a Microsoft Excel spreadsheet. This was done for the whole of the 2019 growing season. Unfortunately, the SPAD 502 meter in the Hoagland lab uses became unavailable for the 2020 growing season because it lost a gasket that needed to be replaced. To compensate for the lack of SPAD measurements in 2020, and to determine if plant chlorophyll/health and disease outbreaks could be quantified using aerial imagery, the plot area was flown using two drones fitted with cameras six times over the growing season. One of the drones contains standard cameras that are programmed to report measurements such as NDVI (normalized difference vegetation index). The other contains several advanced cameras including Lidar to capture images using different techniques and a wide range of wavelengths. The information collected from these drone images will not be reported in this thesis as this is a supplemental pilot study.

Disease ratings

Tomato plants are susceptible to multiple soil-borne and foliar pathogens which cause diseases that negatively impact the yield and quality of tomato fruit. Soil-borne pathogens such as *Verticillium* and *Fusarium* have not yet been detected in these plots and were not the subject of this study. However, many foliar pathogens including *Alternaria dauci* (early blight), *Botrytis cinerea* (gray mold), *Pseudomonas syringae pv. tomato* (bacterial speck) and *Xanthomonas campesiris pv. vesicatoria* (bacterial spot) are regularly observed in these plots. It is extremely difficult to differentiate between the symptoms (lesions on tomato leaves and fruit) of these individual pathogens/diseases in the field, so instead total disease severity in each individual tomato plot (32 total) was recorded 3 times in 2019 and 4 times in 2020. Disease severity refers to the amount of damage to a plant caused by infection from disease. This allowed us to quantify the impacts of the individual treatments and treatment interactions on the severity and spread of diseases over the course of the growing season.

Visual disease ratings for each treatment were collected using the guidance of the Horsfall-Barratt scale (Horsfall and Barrat, 1945). This scale requires the observer to think of the leaf, plant or group of plants as if they were part of a gridded system. Visualizing the amount of imaginary grids containing infected portions of the leaf, plant or plants allows the observer to give a percentage out of 100 for disease severity. These percentages are translated onto the Horsfall-Barratt scale that is seen below (Table 3.9):

Table CHAPTER 3.9. Horsfall-Barratt scale

Score	**Percentage of Observed Disease**
1	0
2	0-3
3	3-6
4	6-12
5	12-25
6	25-50
7	50-75
8	75-87
9	87-94
10	94-97
11	97-100
12	100

These individual disease severity data points were combined to create the area under the disease progress curve (AUDPC). The AUDPC allows the characterization of the overall patterns of disease increase over time and can be done by utilizing various mathematical formulas (Jeger and Viljanen-Rollinson, 2001).

Plant vigor ratings

The overall vigor of plants can also be an indication of their susceptibility to diseases as well as tolerance to various abiotic stress factors and capacity to obtain nutrients and water from soil. Pictures were taken throughout the 2019 & 2020 growing seasons to document above ground growth for each plant. These pictures were given a vigor score on a scale of 1-5 based on the final round of pictures taken when plants were at their most mature stage. Scores of 1 were awarded to the plants that exhibited the poorest above ground growth. 5's were awarded to the fullest, thickest plants. Each value on the five-point scale was assigned a picture that was used to judge the growth pictures. Each variety was assigned its own representative scale as Wisconsin 55 variety plants do not grow to be as tall as Corbarino variety plants. The scale for the two varieties are shown in figure 3.11.

1 – Wisconsin 55

1- Corbarino

2- Wisconsin 55

2- Corbarino

Figure CHAPTER 3.11. 5 point scales for vigor ratings of Corbarino and Wisconsin 55 varieties

Figure 3.11 continued

3- Wisconsin 55

3- Corbarino

4- Wisconsin 55

4- Corbarino

5- Wisconsin 55

5 Corbarino

Tomato fruit harvest

The number and quality of tomato fruit is also an indicator of susceptibility to disease, abiotic stress and the capacity of plants to obtain nutrients and water from soil. Harvesting of fruits began at the sight of the first tomato that had passed the "breakers" stage, indicating that the fruit is beginning to ripen. "Ripe" tomatoes, for the purposes of this experiment, included all ripe tomatoes, as defined by the United States Fresh Fruit and Vegetable Association. These include breakers, turning, pink, light red and red tomatoes. Once the first ripe tomato was spotted, a harvest was planned soon after whereby members of the Hoagland lab met at the research plot early one morning to harvest, count and weigh ripe tomatoes. This was repeated every seven days until the final harvest. Ripe tomatoes were separated into the categories "good" tomatoes and "bad" tomatoes. Good tomatoes were those that were safe to consume and would be acceptable to be sent to market. Bad tomatoes included fruits damaged from disease, insect or animals. (Figures 3.12 & 3.13)

Figure CHAPTER 3.12. Close-up example of a tomato harvested and categorized as "bad" due to insect damage

Figure CHAPTER 3.13. Examples of tomatoes harvested and categorized as "bad" due to insect and disease damage

Tomato plants were terminated and fruit of all size and ripeness were counted and weighed during the last harvest of the season. Tomatoes from the last harvest were separated into categories of ripe ("Red") or large unripe ("Green"). The large unripe tomatoes were expected to be able to mature into ripe tomatoes if the experiment would have been carried later into the harvest season. The harvest schedule for the two growing seasons is shown below (Table 3.10):

Table CHAPTER 3.10. Harvest dates (* indicates date of the final harvest)

2019	**2020**
August 12th	August 5th
August 19th	August 12th
August 26th	August 19th
September 3rd *	August 26th
N/A	September 2nd *

3.2.11 Statistical Analysis

All results were compiled into Microsoft Excel spreadsheets for statistical detection of patterns through rigorous testing. Statistical analyses were conducted using the coding software "R". R is a language and environment for statistical computing and graphics. All individual data sets were analyzed separately by year, to account for year-to-year environmental variability. Spad readings were collected for the 2019 growing season, but not for the 2020 growing season. Individual data sets were subjected to an analysis of variance (ANOVA) to determine if there were significant differences. Independent two-sample t-test analyses were run using the t.test() function within the base package of R when comparing group means for the two dichotomous treatment groups when ANOVA analyses indicated that there were significant differences. For example, composted-incorporated subplots against control subplots and T. harzianum inoculated plants against control plants. ANOVA was carried out using the aov() function within the stats package. ANOVA results were combined with Tukey´s HSD (high significant differences) test. Significance levels of 0.05 ($p < 0.05$) were used to test for significant differences between treatments. Tukey's HSD test was carried out using the function TukeyHSD().

3.3 Results

3.3.1 Soil Test Results

Results of the test conducted at Midwest Labs indicated that in 2019, total soil organic matter was significantly greater in the compost amended plots relative to the non-amended control plots ($p=0.01$), but there were no significant differences in 2020 (Table 3.12). Similarly, results of the 2019 POXC test indicated that the compost treated plots contained a significantly higher amount ($p = 0.021$) of labile, or active, C than the non-amended control soils, but there were no differences between the two treatments in 2020 (Table 3.14).

Table CHAPTER 3.11. Soil chemical properties in soils prior to any amendments during 2019 and 2020.

Year	**Sample**	**Organic Matter %**	**P_1 ppm**	**P_2 ppm**	**K ppm**	**Mg ppm**	**Ca ppm**	**pH**	**CEC meq/100g**
2019	Pre-compost	3.2	8	13	93	609	2381	7.0	17.2
2020	Pre-compost	2.8	14	21	141	581	2345	6.7	16.9

Table CHAPTER 3.12. 2019 and 2020 Midwest Laboratory soil test results for control subplots and compost-amended subplots (Green = Significant difference; Red = No significant difference)

Year	**Sample**	**Organic Matter %**	**P_1 ppm**	**P_2 Ppm**	**K ppm**	**Mg ppm**	**Ca ppm**	**pH**	**CEC meq/100g**
2019	Non-compost	3.7*	17.5*	31.0*	145.8	587.3	2288.0	7.1	16.7
	Compost	7.0*	70.0*	86.0*	193.5	649.8	2540.2	7.1	18.6
2020	Non-compost	2.9	18.0	34.5	121.5	529.8	2123.0	6.7	15.9
	Compost	3.7	24.0	32.5	130.3	553.3	2194.0	6.6	16.9

- * indicates significance is at $P<0.05$

Table CHAPTER 3.13. Mean 2019 and 2020 Midwest Laboratory soil test results for control subplots and compost-amended subplots (Green = Significant difference; Red = No significant difference)

Year	Sample	Organic Matter %	P_1 ppm	P_2 ppm	K ppm	Mg ppm	Ca ppm	pH	CEC meq/100g
2019 & 2020	Non-compost	3.3*	17.6*	31.9*	139.7	572.9	2246.8	7.0	16.5
	Compost	5.4*	58.5*	72.6*	177.7	625.6	2453.7	7.0	18.2

- * indicates significance is at P<0.05
-

Table CHAPTER 3.14. Active soil carbon in soils amended with leaf mold compost treated soils and a non-amended control treatment during 2019 and 2020

	Treatment	Mean POXC Results (mg/kg soil) values	p-value
2019	Non-Compost	667.53	0.02
	Compost	974.42	
2020	Non-Compost	792.56	0.08
	Compost	1232.08	

- Significance is at P<0.05

Soil chemical properties

Results of the soil tests conducted at Midwest Laboratory indicated that in 2019, the compost treated subplots contained significantly higher P_1 ($p = 0.01$) and P_2 levels ($p = 0.03$) as compared to the non-amended control subplots, but there were no significant differences in pH, CEC, K, Mg, or Ca, and there were no differences in any of these properties between the two treatments during 2020 (table 3.12).

Analysis of 2019 inorganic N test results indicate that soils in the compost amended subplots contained significantly higher levels of nitrate & nitrite ($p = 0.045$) (Table 3.15) and ammonia levels ($p = 0.047$) (Table 3.16) when compared against the non-amended control soils. In contrast, during 2020 there were no significant differences in nitrate & nitrite (Table 3.15) nor ammonia levels between these two treatments (Table 3.16). Significance was determined by p-values less than 0.05.

Table CHAPTER 3.15. 2019 & 2020 Inorganic N results comparing nitrate and nitrite levels in plants grown in compost incorporated soils against plants not grown in compost treated soil**.**

	Treatment	**Mean Nitrate + Nitrite (mg N/L) values**	**p-value**
2019	Non-Compost	3.93	0.04
	Compost	7.13	
2020	Non-Compost	15.72	0.24
	Compost	18.39	

- Significance is at P<0.05

Table CHAPTER 3.16. 2019 & 2020 Inorganic N results comparing ammonia levels in plants grown in compost treated soils against plants not grown in compost treated soil.

	Treatment	**Mean Ammonia (mg N/L) values**	**p-value**
2019	Non-Compost	1.23	0.04
	Compost	1.70	
2020	Non-Compost	0.91	0.51
	Compost	0.77	

- Significance is at P<0.05

Soil biological properties

Results of the 2019 FDA assay indicated that microbial activity was significantly greater in the compost treated subplots (p= 0.024) when compared to the non-amended control soils, but there were no significant differences between the two treatments in 2020 (Table 3.17).

Table CHAPTER 3.17. 2019 and 2020 FDA results comparing plants grown in compost incorporated soils against plants not grown in compost incorporated soil.

	Treatment	**Mean FDA Results (mg Fluorescein/g dry soil) values**	**p-value**
2019	Non-Compost	0.155	0.02
	Compost	0.252	
2020	Non-Compost	0.163	0.80
	Compost	0.178	

- Significance is at P<0.05

Results of PCR assays conducted on root zone soils collected during 2019 indicated that *T. harzianum* organisms were present in the soils of every treatment, including soils that were not manually inoculated with *T. harzianum* organisms. Figure 3.14 is a screenshot of one of the PCR reaction gels. While faint, it can be observed that each well has a band at the level of the positive control, indicating that *T. harzianum* is present in the soils of subplots not inoculated, as well as subplots that were treated with inoculations (Figure 3.14). Four additional PCR trials confirmed these results, as well as confirming the presence of *T. harzianum* species in samples that received inoculation, but not compost.

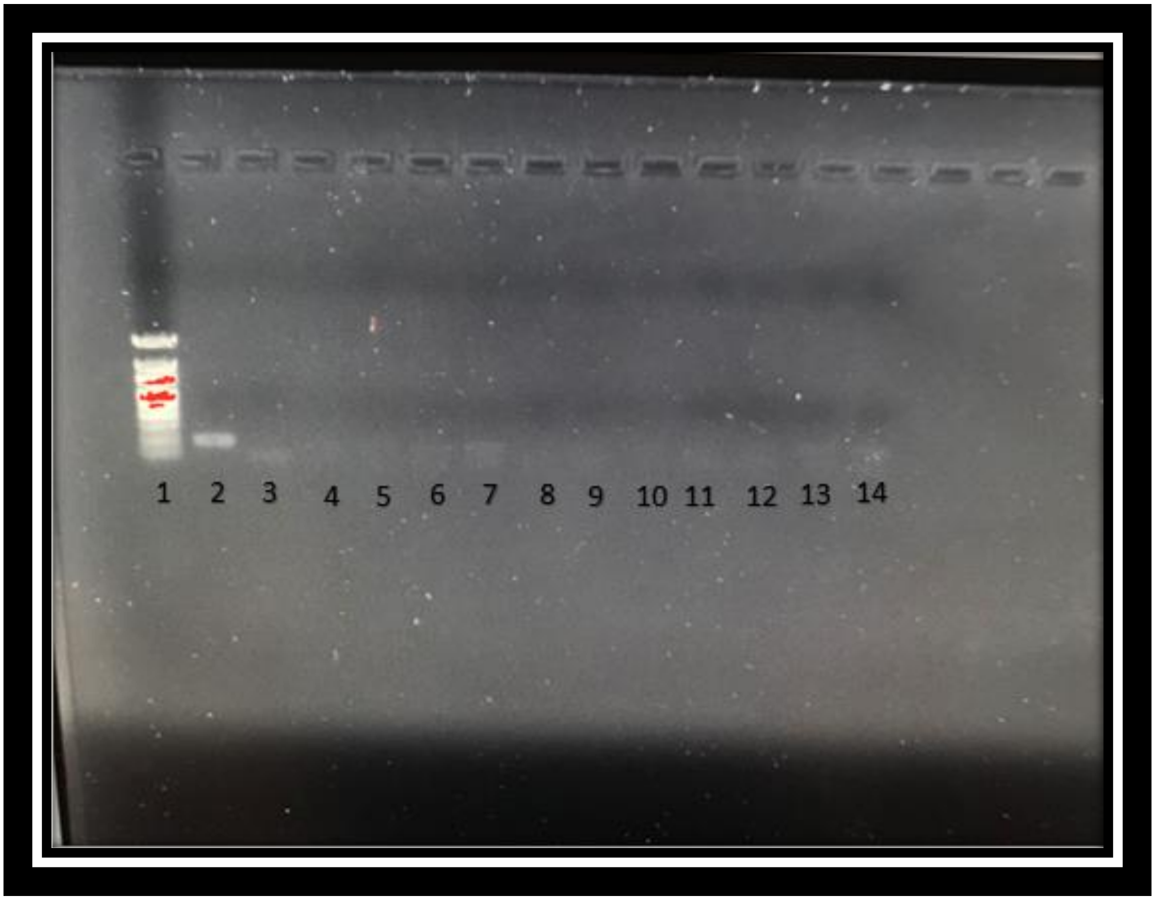


Figure CHAPTER 3.14. Electrophoresis gel demonstrating positive amplification of T. harzianum in root zone soils collected at the base of tomato plants during 2019. Well 2 represents the positive control T. harzianum sample. Well 3 is a negative control well and appears to have had DNA spill over into it, which explains the band. Wells 4-14 contain treatment samples from three of the four treatments. Well 5 represents no compost, no T. harzianum inoculation. Wells 4 and 9-14 represent compost treatments with no T. harzianum inoculation. Wells 6-8 represent compost with T. harzianum inoculation.

Subsequent attempts to quantify the amount of *T. harzianum* in the soil samples using qPCR proved unsuccessful. This was determined by observing successful amplification and melting curves of positive control wells containing 4µL of pure *T. harzianum* DNA, while not observing these curves for positive control wells containing 0.5 µL and 0.2 µL of pure T. harzianum DNA. No successful amplification and melting curves were observed for any of the soil DNA samples tested despite using the maximum amount of DNA allowed in the protocol (7.1 µL). Therefore, soil DNA samples did not contain enough large enough T. harzianum populations for the machinery to detect. Similar results were obtained for 2020, so we attempted to quantify the amount of T. harzianum in these soils using the standard plate technique described in section 3.2.9. Table 3.18 looks at *Trichoderma* populations per gram of soil as found by utilizing the formula in section 3.2.9.

Table 3.318. Table 3.319. 2020 *Trichoderma* population per gram of dried soil based on the treatments of compost and *T. harzianum* inoculation ("N" = No compost, "M" = Compost, "W" = No Trichoderma, "T" = Trichoderma)

Treatment	**Mean *Trichoderma* population per gram of dried soil (10^4)**	**p-value**
MW-MT	2.0 – 4.1	<0.01
NT-MT	2.7 – 4.1	0.08
NW-MT	1.3 - 4.1	<0.01
NT-MW	2.7 - 2.0	0.57
NW-MW	1.3 – 2.0	0.82
NW-NT	1.3 – 2.7	0.15

- Significance is at P<0.05

3.3.2 Plant Test Results

Survival following transplant

Many tomato plants did not survive the transition from greenhouse to the field trial as expected. 2020 was a particularly harsh year meteorologically for transplants. Immediately after transplanting tomato plants in 2020, there was a severe windstorm accompanied by high heat and a lack of moisture which imposed severe abiotic stress. Some of the plants were further stressed due to high sustained high winds in early August of 2020 as a result of the Derecho weather pattern. Results indicated that the *T. harzianum* inoculation resulted in significantly fewer tomato plants dying as a result of transplant stress ($p < 0.01$). When averaged across tomato genotype and not considering the soil amendment treatment, more than three times the amount of control plants died compared to inoculated plants (Table 3.19). In contrast, the leaf mold compost treatment did not influence transplant stress when averaged across *T. harzianum* inoculation and tomato genotype ($p = 0.85$) (Table 3.19). Tomato variety did influence transplant stress, but not significantly ($p = 0.08$), as more than twice the amount of Wisconsin 55 plants died compared to Corbarino when averaged across *T. harzianum* and soil amendment treatments (Table 3.19). Lastly, plants grown in compost treated soils without inoculation died significantly more often than inoculated plants grown in compost treated soils ($p = 0.01$) (Table 3.20).

Table CHAPTER 3.20. 2019 and 2020 plant deaths by *T. harzianum* treatment, compost treatment, variety and compost + *T. harzianum* treatment.

Treatment	**# Deaths**	**p-value**
Non-Trichoderma	24	<0.01
Trichoderma	7	
Non-compost	16	0.85
Compost	15	
Wisconsin 55	21	0.08
Corbarino	10	
Compost, No Trichoderma	14	See table 3.20
No Compost, No Trichoderma	10	
No Compost, Trichoderma	5	
Compost, Trichoderma	2	

- Significance is at $P<0.05$

Table CHAPTER 3.21. Statistical analyses comparing groups based on the treatments of compost and *T. harzianum* inoculation (“N” = No compost, “M” = Compost, “W” = No Trichoderma, “T” = Trichoderma)

Treatment	**Deaths**	**p-value**
MW-MT	14 - 2	>0.01
NT-MW	5 – 14	0.12
NW-MT	10 - 2	0.22
NW-NT	10 - 5	0.69
NW-MW	10 – 14	0.69
NT-MT	5 - 2	0.84

- Significance is at P<0.05

Tables 3.21 and 3.22 depict plant death rates for each variety grouped by *T. harzianum* inoculation and compost treatment for the years 2019 and 2020. There was a clear interaction between tomato genotype and *T. harzianum* inoculation, with significantly fewer deaths in Wisconsin 55 plants treated with *T. harzianum*. In contrast, there was no significant differences in deaths between Corbarino plants treated or not with *T. harzianum.*

Table CHAPTER 3.22. 2019 plant deaths by variety + *T. harzianum* treatment and variety + compost treatment

2019		
Variety & Treatment	**# Deaths**	**p-value**
Wisconsin 55 (Control)	1	0.08
Wisconsin 55 (Trichoderma inoculated)	5	
Corbarino (Control)	0	1.00
Corbarino (Trichoderma inoculated)	0	
Wisconsin 55 (Control)	2	0.64
Wisconsin 55 (Compost)	4	
Corbarino (Control)	0	1.00
Corbarino (Compost)	0	

- Significance is at P<0.05

Table CHAPTER 3.23. 2020 plant deaths by variety + *T. harzianum* treatment and variety + compost treatment

2020		
Variety & Treatment	**# Deaths**	**p-value**
Wisconsin 55 (Control)	13	<0.01
Wisconsin 55 (Trichoderma inoculated)	2	
Corbarino (Control)	6	0.93
Corbarino (Trichoderma inoculated)	4	
Wisconsin 55 (Control)	8	0.99
Wisconsin 55 (Compost)	7	
Corbarino (Control)	5	1.00
Corbarino (Compost)	5	

- Significance is at P<0.05

SPAD Readings

Analysis of 2019 Spad meter data reveals that plants grown in compost treated subplots exhibited significantly higher Spad readings in July (p= 0.02) and August (p < 0.01) (Table 3.23). In contrast, there was no significant differences in SPAD meter readings of tomato leaves during July (p= 0.94) or August (p= 0.32) in response to the T. harzianum inoculation treatment (Table 3.24).

Table CHAPTER 3.24. 2019 Spad 502 meter readings for July and August comparing plants grown in compost incorporated soils against plants not grown in compost incorporated soil.

	July average	**July p-value**	**August average**	**August p-value**
Control	46.2	0.02	41.94	<0.01
Compost	49.1		44.10	

- Significance is at P<0.05

Table CHAPTER 3.25. 2019 Spad 502 results comparing plants receiving T. harzianum inoculations against plants that did not receive inoculations.

	July average	**July p-value**	**August average**	**August p-value**
Control	47.6	0.94	43.4	0.33
Trichoderma	47.7		42.6	

- Significance is at P<0.05

3.3.3 Disease Ratings

The area under the disease pressure curve (AUDPC) calculated during the 2019 growing season indicated that there was no difference between tomato plants grown in the compost amended versus non-amended control treatments ($p = 0.43$), though there was a significant difference between these soil treatments ($p < 0.01$) during the 2020 growing season (Table 3.25). When comparing differences in the AUDPC in response to the *T. harzianum* inoculant, there were no significant differences between the treatment during 2019 ($p=0.08$) or 2020 ($p = 0.36$) (Table 3.25). In addition, ANOVA test results indicated that there were no significant differences during 2019 ($p=0.777$) or 2020 ($p = 0.09$) when comparing AUDPC scores between the four treatment groups for each variety (Tables 3.26 and 3.27).

Table CHAPTER 3.26. 2019 & 2020 Disease ratings comparing (1) plants grown in compost-treated soils to control plants, and (2) plants given T. harzianum inoculations to control plants that did not.

	Treatment	**Mean Disease Rating**	**p-value**
2019	Non-Compost	3.5	0.79
	Compost	3.7	
2020	Non-Compost	5.4	<0.01
	Compost	3.1	
2019	Non-inoculated	3.8	0.44
	Inoculated	3.4	
2020	Non-inoculated	4.7	0.36
	Inoculated	3.8	

Analysis of treatment groups reveals that no significant differences exist between any of the groups for both the 2019 and 2020 growing seasons.

Table CHAPTER 3.27. 2019 ANOVA disease rating comparisons between treatment groups ("N" = No Compost, "M" = Compost, "W" = No Trichoderma Inoculation, "T" = Trichoderma inoculation, "1" = Wisconsin 55 variety, "2" = Corbarino variety)

	NW1	NT1	MW1	MT1	NW2	NT2	MW2	MT2
NW1								
NT1	None							
MW1	None	None						
MT1	None	None	None					
NW2	None	None	None	None				
NT2	None	None	None	None	None			
MW2	None	None	None	None	None	None		
MT2	None	None	None	None	None	None	None	

Table CHAPTER 3.28. 2020 disease rating comparisons between treatment groups ("N" = No Compost, "M" = Compost, "W" = No Trichoderma Inoculation, "T" = Trichoderma inoculation, "1" = Wisconsin 55 variety, "2" = Corbarino variety)

	NW1	NT1	MW1	MT1	NW2	NT2	MW2	MT2
NW1								
NT1	None							
MW1	None	None						
MT1	None	None	None					
NW2	None	None	None	None				
NT2	None	None	None	None	None			
MW2	None	None	None	None	None	None		
MT2	None	None	None	None	None	None	None	

Vigor Ratings

Visual analysis of plant shoot growth and health was assigned for each plant throughout the growing season. Two-step independent t-tests were run for the final vigor ratings of each growing season. Results of these analyses indicate that the leaf mold compost treatment significantly increased vigor of tomato plants compared to plants grown in the non-amended control plots during both 2019 ($p<0.01$) and 2020 ($p<0.01$) (Table 3.28). In contrast, there were no significant differences in plant vigor during either year when comparing plants inoculated with *T. harzianum* or a sterile water control (3.31).

Table CHAPTER 3.29. 2019 & 2020 Vigor ratings comparing (1) plants grown in compost-treated soils to control plants, and (2) plants given *T. harzianum* inoculations to control plants that did not.

	Treatment	**Mean Vigor Rating**	**p-value**
2019	Non-Compost	2.0	<0.01
	Compost	4.0	
2020	Non-Compost	3.4	<0.01
	Compost	4.7	
2019	Non-inoculated	2.9	0.78
	Inoculated	3.1	
2020	Non-inoculated	4.1	0..83
	Inoculated	4.1	

Analysis of 2019 vigor ratings indicate that *T. harzianum* inoculation and genotype do not appear to play a significant role when understanding what variables affected growth and development (Tables 3.29 and 3.30). 2020 results show a significant difference between every comparison made between a compost-treated subplot and a control plot. In all cases from 2019 and 2020, the compost-treated plants exhibited higher vigor ratings compared to control plants.

Table CHAPTER 3.30. 2019 vigor rating comparisons between treatment groups ("N" = No Compost, "M" = Compost, "W" = No Trichoderma Inoculation, "T" = Trichoderma inoculation, "1" = Wisconsin 55 variety, "2" = Corbarino variety)

	NW1	NT1	MW1	MT1	NW2	NT2	MW2	MT2
NW1								
NT1	None							
MW1	None	Sig Dif						
MT1	None	Sig Dif	None					
NW2	None	None	None	None				
NT2	None	None	None	Sig Dif	None			
MW2	Sig Dif	Sig Dif	None	None	Sig Dif	Sig Dif		
MT2	Sig Dif	Sig Dif	None	None	Sig Dif	Sig Dif	None	

Table CHAPTER 3.31. 2020 disease rating comparisons between treatment groups ("N" = No Compost, "M" = Compost, "W" = No Trichoderma Inoculation, "T" = Trichoderma inoculation, "1" = Wisconsin 55 variety, "2" = Corbarino variety)

	NW1	NT1	MW1	MT1	NW2	NT2	MW2	MT2
NW1								
NT1	None							
MW1	Sig Dif	Sig Dif						
MT1	Sig Dif	Sig Dif	None					
NW2	None	None	Sig Dif	Sig Dif				
NT2	None	None	Sig Dif	Sig Dif	None			
MW2	Sig Dif	Sig Dif	None	None	Sig Dif	Sig Dif		
MT2	Sig Dif	Sig Dif	None	None	Sig Dif	Sig Dif	None	

3.3.4 Trichoderma inoculation effect on seedling growth

Seedlings from one of the two trays for each variety received 1 mL of the *T. harzianum* inoculation around the base of the plant. This was done 23 days after sewing in 2019 and 16 days after sewing in 2020. Unfortunately, seedling growth pictures from 2019 were lost when a personal cell phone containing the photos experienced a factory-recalled malfunction between the 2019 and 2020 growing seasons. Fortunately, 2020 seedlings photos have survived and provide visual evidence of the beneficial growth effects of *T. harzianum* inoculations. Figures 3.15-3.18 were taken 20 days after inoculation on May 22, 2020.

Figure CHAPTER 3.15. Wisconsin 55 seedlings that did not receive 1 mL *T. harzianum* inoculation

Figure CHAPTER 3.16. Wisconsin 55 seedlings that received 1 mL *T. harzianum* inoculation

Figure CHAPTER 3.17. Corbarino seedlings that did not receive 1 mL *T. harzianum* inoculation

Figure CHAPTER 3.18. Corbarino seedlings that received a 1 mL *T. harzianum* inoculation

Although difficult to tell from figures 3.15-3.18, heights differed for control and inoculated seedlings for both Wisconsin 55 and Corbarino varieties. The average height of Wisconsin 55 seedling was around 4.5 inches for the tray that did not receive inoculations. This is much shorter than the observed 7 inch average for the inoculated Wisconsin 55 tray. Results were less stark from the Corbarino variety tomatoes, but differences still existed. The average height of Corbarino seedlings was around 6 inches for the tray that did not receive inoculation. The inoculated Corbarino tray averaged around 7 inches of height.

Figure CHAPTER 3.19. Wisconsin 55 seedlings the day of planting: *T. harzianum* inoculated (pictured left) and non-*T. harzianum* inoculated (pictured right)

Figure CHAPTER 3.20. Corbarino seedlings the day of planting: *T. harzianum* inoculated (pictured left) and non-*T. harzianum* inoculated (pictured right)

Visual height differences between inoculated Wisconsin 55 seedlings and their non-inoculated counterparts were quite stark on the day of planting, as can be seen from Figure 3.19. Height differences between inoculated and non-inoculated Corbarino plants are less noticeable, although they still can be seen (see Table 3.20).

3.3.5 Tomato fruit yield and quality

Because of high death rates following transplanting, particularly during 2020 growing season, the yield data is reported here based on the average for an individual tomato plant within each treatment group. This was calculated by dividing each subplot's yield data by the number of plants that survived death from transplant shock.

Compost treatment

Table CHAPTER 3.32. 2019 harvest results per plant comparing fruit production of plants by *T. harzianum* treatment and variety

2019 Harvest results by Leaf Compost and Variety (per plant)							
Sample	Living plants	Total Ripe	Total Weight Ripe	Total Bad	Total Weight Bad	Good:Bad Ratio Ripe	Green @ Final Harvest
	#	#	(kg)	#	(kg)	Ratio	(kg)
Control (Wisc. 55)	43	*2.5	*0.26	2.3	0.13	1.1	0.54
Compost (Wisc. 55)	47	*5.1	*0.63	2.4	0.30	2.1	0.85
Control (Corbarino)	48	*38.4	*0.86	3.4	0.07	11.4	*0.42
Compost (Corbarino)	48	*66.0	*1.43	4.3	0.10	15.2	*0.88

- * indicates significance at P<0.05

Table CHAPTER 3.33. 2020 harvest results per plant comparing fruit production of plants by *T. harzianum* treatment and variety

2020 Harvest results by Leaf Compost and Variety (per plant)							
Sample	Living plants	Total Ripe	Total Weight Ripe	Total Bad	Total Weight Bad	Good:Bad Ratio Ripe	Green @ Final Harvest
	#	#	(kg)	#	(kg)	Ratio	(kg)
Control (Wisc. 55)	35	18.4	2.89	2.5	2.32	7.3	2.16
Compost (Wisc. 55)	46	17.3	2.39	2.3	2.19	7.6	2.03
Control (Corbarino)	42	69.0	1.58	3.5	2.05	19.4	2.02
Compost (Corbarino)	44	81.0	1.85	4.0	2.07	20.4	2.02

- * indicates significance at P<0.05

Trichoderma treatment

Table CHAPTER 3.34. 2019 harvest results per plant comparing fruit production of plants by *T. harzianum* treatment and variety

2019 Harvest results by Trichoderma and Variety (per plant)							
Sample	Living plants	Total Ripe	Total Weight Ripe	Total Bad	Total Weight Bad	Good:Bad Ratio Ripe	Green @ Final Harvest
	#	#	(kg)	#	(kg)	Ratio	(kg)
Control (Wisc. 55)	43	3.5	0.40	3.0	0.27	1.2	0.60
Compost (Wisc. 55)	47	4.2	0.50	1.8	0.17	2.3	0.76
Control (Corbarino)	48	50.2	1.10	4.1	0.09	12.3	0.58
Compost (Corbarino)	48	54.3	1.19	3.5	0.07	15.5	0.70

- * indicates significance at P<0.05

Table CHAPTER 3.35. 2020 harvest results per plant comparing fruit production of plants by *T. harzianum* treatment and variety

2020 Harvest results by Trichoderma and Variety (per plant)							
Sample	Living plants	Total Ripe	Total Weight Ripe	Total Bad	Total Weight Bad	Good:Bad Ratio Ripe	Green @ Final Harvest
	#	#	(kg)	#	(kg)	Ratio	(kg)
Control (Wisc. 55)	35	18.4	2.89	2.5	2.32	7.3	2.16
Compost (Wisc. 55)	46	17.3	2.39	2.3	2.19	7.6	2.03
Control (Corbarino)	42	69.0	1.58	3.5	2.05	19.4	2.02
Compost (Corbarino)	44	81.0	1.85	4.0	2.07	20.4	2.02

- * indicates significance at P<0.05

4 treatment groups

Table CHAPTER 3.36. 2019 harvest results per plant comparing fruit production of Wisconsin 55 variety plants by treatment groups

2019 4 Treatment Groups (Wisconsin 55) (per plant)							
Sample	Living plants	Total Ripe	Total Weight Ripe	Total Bad	Total Weight Bad	Good:Bad Ratio Ripe	Green @ Final Harvest
	#	#	(kg)	#	(kg)	Ratio	(kg)
No Compost, No Tricho	23	0.8	0.08	0.8	0.04	*1.0	*0.11
Compost, No Tricho	20	1.0	0.10	0.8	0.10	1.3	0.22
No Compost, Tricho	23	*0.4	*0.04	0.3	0.02	1.2	0.14
Compost, Tricho	24	*1.7	*0.20	0.6	0.06	*2.8	*0.24

- * indicates significance at P<0.05

Table CHAPTER 3.37. 2020 harvest results per plant comparing fruit production of Corbarino variety plants by treatment groups

2019 4 Treatment Groups (Corbarino) (per plant)							
Sample	Living plants	Total Ripe	Total Weight Ripe	Total Bad	Total Weight Bad	Good:Bad Ratio Ripe	Green @ Final Harvest
	#	#	(kg)	#	(kg)	Ratio	(kg)
No Compost, No Tricho	24	10.5	0.25	1.0	0.02	*5.6	*0.08
Compost, No Tricho	24	14.6	0.30	1.1	0.03	6.6	0.21
No Compost, Tricho	24	*8.8	0.19	0.8	0.01	5.7	0.13
Compost, Tricho	24	*18.4	0.42	1.0	0.02	*8.7	*0.22

- * indicates significance at P<0.05

Table CHAPTER 3.38. 2020 harvest results per plant comparing fruit production of Wisconsin 55 variety plants by *T. harzianum* treatment and variety

2020 4 Treatment Groups (Wisconsin 55) (per plant)							
Sample	Living plants	Total Ripe	Total Weight Ripe	Total Bad	Total Weight Bad	Good:Bad Ratio Ripe	Green @ Final Harvest
	#	#	(kg)	#	(kg)	Ratio	(kg)
No Compost, No Tricho	18	4.2	0.62	0.5	0.47	8.4	*0.44
Compost, No Tricho	15	**5.7	0.95*	0.4	0.79	14.3	*0.73
No Compost, Tricho	22	*3.6	0.52*	0.1	0.52	36.0	0.48
Compost, Tricho	24	**4.9	0.67	0.7	0.57	7.0	0.54

- * indicates significance at P<0.05

Table CHAPTER 3.39. 2020 harvest results per plant comparing fruit production of Corbarino variety plants by *T. harzianum* treatment and variety

2020 4 Treatment Groups (Corbarino) (per plant)							
Sample	Living plants	Total Ripe	Total Weight Ripe	Total Bad	Total Weight Bad	Good:Bad Ratio Ripe	Green @ Final Harvest
	#	#	(kg)	#	(kg)	Ratio	(kg)
No Compost, No Tricho	21	*11.2	*0.26	0.7	0.37	16.0	0.36
Compost, No Tricho	21	**23.3	**0.51	0.5	0.66	46.6	0.65
No Compost, Tricho	22	16.4	0.37	0.9	0.37	44.3	0.36
Compost, Tricho	23	**23.1	**0.53	0.5	0.63	46.2	0.62

- * indicates significance at P<0.05

Determining statistical differences for the four treatment groups was done using ANOVA statistical tests. Table 3.39 shows statistically significant results for treatment groups on both an overall and per plant yield basis when combining 2019 and 2020 data. These results indicate that the treatments played a primary role in the observed effects because per plant data shows the same effect as overall data. This eliminates the possibility that results were only observed due to the uneven number of plants that survived per treatment. It is interesting to note that every observed statistical difference is between a non-composted subplot and a composted subplot. Inoculation of *T. harzianum* does not appear to play a major factor in the effects.

Table CHAPTER 3.40. Statistically significant results for subplots observing overall and per plant yield data ("Tricho" = *T. harzianum* inoculation)

Variety	**Subplots**	**Effect**	**p-value**
Corbarino	No compost, Tricho < Compost, Tricho	(#) Good fruits	0.03
Corbarino	No compost, No Tricho < Compost, Tricho	(#) Good fruits	0.01
Corbarino	No compost, No Tricho < Compost, Tricho	(kg) Good fruits	0.03
Corbarino	No compost, No Tricho < Compost, Tricho	(kg) Green fruits @ final harvest	0.02
Wisc. 55	No compost, Tricho < Compost, Tricho	(#) Good fruits	0.01
Wisc. 55	No compost, No Tricho < Compost, Tricho	(kg) Green fruits @ final harvest	> 0.01
Wisc. 55	No compost, No Tricho < Compost, No Tricho	(kg) Green fruits @ final harvest	0.02

Table 3.40 shows statistically significant results for treatment groups on just an overall basis. These results were not observed on a per plant basis. This indicates that the following results were statistically significant primarily due to the discrepancy in plant deaths between the treatments. These differences only exist between non-composted subplots and compost subplots. *T. harzianum* inoculations do not affect significant results as half of the results with lower production were inoculated.

Table CHAPTER 3.41. Statistically significant results for subplots observing only overall yield data ("Tricho" = *T. harzianum* inoculation)

Variety	**Subplots**	**Effect**	**p-value**
Corbarino	No compost, No Tricho < Compost, No Tricho	(kg) Green fruits @ final harvest	0.03
Wisc. 55	No compost, Tricho < Compost, Tricho	(#) Good fruits	0.01
Wisc. 55	No compost, No Tricho < Compost, Tricho	(kg) Green fruits @ final harvest	> 0.01
Wisc. 55	No Compost, Tricho < Compost, Tricho	(kg) Green fruits @ final harvest	0.01

3.4 Discussion

3.4.1 Influence of leaf mold compost on plant and soil health

The primary goal of this project was to determine if leaf mold compost could improve the health of a degraded urban soil and increase the resilience of tomato plants against biotic and abiotic stresses that can reduce crop yield. The results from this two-year experiment support this assertion and clearly demonstrate there exist many benefits for farmers and gardeners who utilize composted leaves from municipal sources on their operations. However, municipal waste is sometimes found alongside the leaves despite a city's best efforts to ensure that only leaves enter their collection facilities. A few waste products were found among the leaf compost piles for both the 2019 and 2020 growing season. The majority of waste found was plastic wrappers of all sorts, including shreds of candy and hamburger wrappers. Small amounts of unintended municipal waste are inevitable and harmless for the most part, but a swift look through a municipal leaf compost pile before application may be necessary to check for harmful objects. Upon a swift inspection, a metal chain was found among the 2020 leaf compost pile (Figure 3.21). Moreover, since land in some urban areas can be contaminated by heavy metals, farmers and gardeners should consider getting composts derived from municipal waste streams tested to ensure that the material is safe and will not inadvertently contaminate their fields.

Figure CHAPTER 3.21. Chain found in the 2020 leaf compost pile

Amending soils with leaf compost improves soil health

The results of two years' worth of soil testing demonstrate that tilling leaf compost into the soil improves certain biogeochemical properties of the soil, while other properties remain less affected. One of the most dramatic soil benefits observed were large increases in total SOM, which was unexpected given the short duration of this study.

Non-composted subplots averaged 3.3% total SOM and composted plots averaged 5.4%. While a 2.1% increase in total SOM content might not seem like a monumental jump, the benefits of such a jump could, in fact, be monumental. This is particularly true if these benefits are observed on a large scale. SOM is not itself a nutrient that the plant can take up for use, but they do gain access to these nutrients as the active fraction of SOM slowly decomposes while the remaining stable fraction contributes to the soils' nutrient holding capacity (Oregon State University Extension, 2019). Increasing the amount of SOM also has the beneficial effect of building aggregates in the soil. Proper soil aggregation is crucial because it creates pores for the retention and exchange of air and water (USDA NRCS, 1996). Moreover, SOM can retain water at up to 90% of its weight (Funderburg, 2001). These two benefits, aggregation and water holding capacity, work together to build a third benefit that SOM provides in the soil: erosion prevention. The soil is a producer's most valuable asset and serious issues arise when topsoil transports off of a farm onto an undesired location. Studies show that increasing SOM from just 1 to 3% can prevent between 20-33% of soil erosion (Funderburg, 2001). Our study results indicate that amending a soil with a 3-year leaf compost can significantly increase total SOM pools, thereby increasing a soil's ability to aggregate, its water holding capacity and its ability to safeguard against erosion.

SOM is an important indicator of soil health and quality. However, SOM is a loosely defined term lacking constant chemical composition. For this reason, soil organic carbon (SOC) is commonly measured and reported in scientific literature because carbon (C) is the most prevalent element that makes up soil organic matter (Weil et al., 2003). Because total SOM pools are generally very slow to change, soil scientists often quantify labile or active SOM or C pools instead because they tend to change more quickly and are therefore a better indicator of how management practices affect soil health (Calderon et al., 2017). Labile C fractions of the soil "fuel the food web and therefore greatly influence nutrient cycles as well as many other biologically related soil properties" (Weil et al., 2003). For example, more efficient cycling of nutrients increases the availability of nutrients when plants need them most, and reduces loss to the environment (Hoagland et al., 2008; Rudisill et al., 2015). Stimulating the abundance and activity of soil microbial communities with active SOC can also directly support the health of plants by suppressing pathogens that cause disease (Schlatter et al., 2017).

The soil permanganate oxidizable carbon (POXC) test quantifies the amount of labile C and is frequently used as a measure of soil health. POXC test results from the 2019 and 2020 growing seasons evaluated in this trial demonstrate that amending soils with leaf compost amendments can lead to significantly higher levels of labile soil C. Soils treated with leaf compost averaged 1103.25 mg C kg^{-1} soil while non-amended control soils averaged only 730.04 mg C kg^{-1} soil. 730.04 mg C kg^{-1} soil is not a particularly low value for a soil's labile C. In fact, it is considered middle-to-high indicating that the soils at this site have already been improved by the integration of winter and summer cover crops. The addition of the leaf mold compost also increased soil microbial activity in this trial, as indicated by significant increases in FDA. Increasing soil microbial activity to acceptable levels should be a primary focus for many modern farmers. The myriad benefits a thriving microbial ecosystem provides to the farmer often go unnoticed due to their microscopic nature. "Out of sight, out of mind" is a logical fallacy that farmers and agricultural experts worldwide must avoid if they are to maximize efficiency of their soils.

Like most field experiments, year to year variability can influence the results and this trial was no exception, as indicated by the lack of significant changes in soil health properties observed during the 2020 growing season. We attempted to hold the total amount of leaf mold compost constant during both years, by applying three inches over the surface of each sub-plot. However, one potential difference between the two years may lie in the fact that the original plan was to incorporate six inches of compost to each plot as suggested by our farmer collaborator, Mr. Dan Perkins. This was attempted during the 2019 field preparation, but we quickly realized that it was too much and reduced the pile down to three inches by manually raking off the top three inches. In addition, the original idea was to use a 749-gas powered BCS tractor with a harrow to till the compost into the ground, but the amount proved too difficult for the BCS tractor harrow to handle. Consequently, the decision was made to utilize the research farm's tractor and tiller implement to incorporate the compost. As a result of these activities, it is plausible that more total compost was incorporated in 2019 relative to 2020 since the pile was likely condensed by all the foot and implement traffic. In addition, during the 2020 growing season, it appeared that the compost amendment was better incorporated into the soil since we only relied on the tractor and tiller to incorporate the compost, which would have diluted the total amount of compost which was collected during soil sampling events. Regardless of our ability to capture changes in soil health in response to the leaf mold compost amendment in both years, the benefits to plant health and productivity were clearly apparent as described below.

Potential contributions of leaf mold compost to plant fertility needs

Increasing total and active fractions of SOM by amending soil with leaf mold compost can also have important implications for fertility programs. 10-40 lb N., 4-7 lb P, and 2-3 lb S are released per acre each summer for roughly every 1% increase in soil organic matter (Brady and Weil, 2009; University of Massachusetts Extension, n.d.). The typical amount of N released per acre for a soil with 4% organic matter is conservatively approximated to be 80 lb (University of Massachusetts Extension, n.d.). At SOM levels of 5.4%, the leaf compost-incorporated subplots should expect an increased release of 21-84 lb N, 8-14 lb P and 4-6 lb S during the growing season compared to non-composted plots. 84 lb N per acre is over half of the recommended 150 lb N per acre typically recommended for maximum tomato fruit yield and quality (Miyao, 2013). 8-14 lb P is a fair amount considering only 44.6 lb P per acre is all that is necessary for field grown crops of all kinds (Korob, 2018b). Only around 1.2 lb S is required per ton of tomato fruit so an additional 4-6 lb S released every summer could greatly reduce the amount of S needed to be applied (Korob, 2018a).

As every grower knows, fertilizer inputs cost money. Fertilizer prices are quite volatile and fluctuate rapidly throughout the year but the latest USDA ERS data from 2014 shows that anhydrous ammonia was $0.43 per lb. This means 100 lb per acre of anhydrous ammonia is $43. The nutrient content of synthetic fertilizers is not 100% so 100 lb of anhydrous ammonia does not equate to 100 lb N to a field. More synthetic fertilizer must be purchased to supply a field with the desired amount of nutrient. While $43 per 100 lb may not seem like much at first glance, agronomic expenses add up quickly, especially for large-scale farming operations. Farmers growing crops of all kinds can save hundreds or even thousands of dollars each growing season from the free release of nutrients by decomposing organic matter. Tomato production, in particular, is typically quite expensive as it is very labor intensive, so growers need to look for any financial edge they can find.

Leaf compost appears to be one practice in which producers can dramatically cash in, especially as leaves are often a free input. Many cities will transport municipal leaf collections directly to farming operations free of charge. Dan Perkins, the Demotte, Indiana farmer whose leaf compost was utilized for the experiment, wrote that the leaves he used to create the compost were "Free. We are really close to town so it saves them a ton of money to not have to haul as far or pay tipping fees at a landfill or maintain their own brush site." Urban agriculture can take advantage of this great resource of compostable material because, by definition, these operation find themselves within city limits. Presumably, the shorter distance a city has to haul a shipment of leaves, the more likely it is to agree to freely hand over these leaves. Agricultural producers of any size have a lot to gain in their soils and pocketbooks were they to tap into this potentially free resource.

It is important to test soils in a timely fashion as recommended by experts to ensure that excess fertilizer is not being applied in amendments like compost. Excess fertilizer, particularly water-soluble N, is harmful to both the environment and a farming operation's bottom line. Moreover, farmers and gardeners who try to rely exclusively on compost to meet plant fertility needs can end up oversaturating their soil in P, because plants need more N relative to P. Many composts, especially those derived from animal manures, contain roughly equal concentrations of these two important nutrients. In a recent survey of 25 urban farms in the Netherlands managed primarily using composted fertility amendments, nutrient applications of N, P and K severely exceeded crop needs, and P in particular, was 76% greater than the legal limit (Wielemaker et al., 2019). Excess soil P can lead to water quality problems such as eutrophication and negatively impact the health of plants by interfering with the uptake of other critical plant nutrients like calcium. One of the potential benefits of using leaf mold compost is that it has a low amount of P relative to N, so it could help growers supply critical nutrients like N while avoiding the build-up of P.

Interpreting the results of a soil test are often difficult for growers and one area of confusion is figuring out what P_1 and P_2 values represent and what the difference is between the two. P_1 values are often referred to as "Weak Bray", while P_2 values are "Strong Bray". P_1 values refer to the readily available amount of P in the soil that a plant can take up and is the primary value used to make P application recommendations. P_1 levels below approximately 15 ppm are considered low, 15-25 ppm are considered medium and levels above 25 ppm are considered high (Miyao, 2013). P_2 values refer to the amount of P that is not initially available to the plant, but will become available to the plant throughout the growing season. An unusually high P_2:P_1 ratio indicates that most of the P in highly insoluble forms and will not become available for plant uptake.

During the 2019 growing season, the leaf mold compost amendment significantly increased the amount of P_1 and P_2 values in soil. Money saved from the addition of available P in the soil is one way in which growers can benefit from incorporating leaf compost into their soils. Supplying sufficient P to plants is very important because P is a major macronutrient essential to growth and crop production. P is essential for taking in the sun's energy and converting it to forms that can be used for growth and reproduction (Sawyer, 2000). P deficiency symptoms include: stunted growth, delayed maturity and poor fruits and seed development (Nathan, 2016). P deficiency is often observed in low fertility and low organic matter content soils in early spring as cool soil temperatures inhibit the activity of the soil microorganisms that release nutrients (Iowa State Extension, n.d.). Leaf compost-incorporated subplots during the 2019 growing season had significantly greater total SOM so it should not come as a major shock that P_1 and P_2 values were higher as well. To this end, leaf compost appears to be a potential alternative amendment for treating soils with chronically low levels of P. However, P_1 and P_2 levels of 58.5 and 72.6 ppm, respectively, are quite high for soils. As described above, excessive P is an issue as this circumstance can lead to difficulties for a plant to take up essential micronutrients (Provin and Pitt, 2019). In addition, soils with excess P can be a point source of pollution. Similar to N, excess P can end up in lakes, ponds and rivers where they can promote algal bloom and eutrophication. Consequently, growers need to carefully consider how excessive applications of compost can lead to soil P enrichment. During the 2020 growing season in this trial, differences in P_1 and P_2 were not significantly different between the composted and non-amended plots, indicating that an uncompressed three-inch layer of leaf mold compost can improve soil health without leading to excessive P levels in soil.

Measuring nitrate (NO_3-), nitrite (NO_2-) and ammonium (NH^{4+}) levels in a soil is very important as these forms of N are vital in the N cycle and they represent the forms of N that are available for plant uptake. Nitrogen is a key building block for plant DNA and also the most common limiting nutrient in plant growth and development. NH^{4+} is the first form of plant available N released during the microbially-mediated soil N cycle. NH^{4+} is then further mineralized by soil microbes into NO_2- and then NO_3-. NO_2- is not useable by plants directly (Cleemput and Samater, 1995), though plants heavily rely on NO_{3-} as their most preferred N source. NH^{4+} and NO_{3-} can also be taken up by other soil microbes and immobilized in their tissues, thereby reducing availability to plants. This occurs in the presence of organic materials that have high C:N ratios since, unlike plants, soil microbes are limited in C rather than N. Because NO_{3-} is negatively charged like most soil clays and highly processed SOM, it can be leached from the soil profile, especially when water availability is high. Therefore, careful N management is a critical consideration for maximizing crop yield and protecting environmental health.

During the 2019 growing season, soil concentrations of NH_{4+}, NO_{-2} and NO_{-3} were significantly greater in the compost amended plots, indicating that this leaf mold compost can help supplement plant N needs. However, the levels of these N compounds were not excessive enough to indicate potential problems. Tomato leaves grown in compost amended plots during 2019 growing season exhibited greater SPAD meter readings, providing evidence that the compost was aiding in plant N acquisition. Relative chlorophyll content in leaves quantified using a SPAD meter is an efficient way to evaluate plant N status in many crops and some tree species (Bonneville, 2006). Unfortunately, SPAD measurements were not collected during the 2020 growing season since the meter was not operational in time for use in July and August. However, given increases in the vigor and yield in the compost amended plots in year, we expect that the compost helped the plants obtain N either directly or through indirect processes. Biologically healthier soils have been found to increase crop yields per unit of mineral N fertilizer (Wade et al., 2020), by processes that include increasing SOM and improving soil tilth which allows plant roots to better explore the soil profile. Wade et al. (2020) do note that in most cases, biologically healthier soils cannot be relied upon to replace the use of mineral N fertilizers. However, increasingly efficient N use by plants and N release in the soil by microorganisms means long-term financial savings for farming operations.

Relationships between leaf mold compost and tomato crop health and productivity

The biggest challenge facing organic tomato growers is managing pathogens that cause plant diseases (Hoagland et al., 2015). Interestingly, while we did not observe visible reductions in damage caused by foliar pathogens during 2019, we did observe evidence of lower disease pressure in compost amended plots in 2020. Visual assessments of disease severity in field trials is challenging and ratings can be subjective since it is difficult for the human eye to accurately quantify infection levels (Bock et al., 2020). Therefore, it is possible that there were decreases in disease severity during the 2019 growing season as well that we were not able to effectively capture it with our rating system. Significantly greater vigor ratings during both growing seasons in compost amended plots helps support this assertion. Healthier, stronger plants with greater access to nutrients tend to ward off diseases better than weaker, feebler ones. Many studies have demonstrated that amending soils with certain types of compost can increase a soils 'disease suppressive' capacity by increasing the abundance and activity of microbes that can suppress pathogens directly and/or indirectly by stimulating ISR (Schlatter et al., 2017). We did not directly measure changes in the composition and activity of soil microbial communities with disease suppressive activity in this trial. However, we did observe the presence of *Trichoderma* in all soils using PCR. This indicates that there are native populations of these beneficial fungi in these soils that could have been stimulated by the leaf mold compost, though further research would be needed to support this assumption. It is unclear at this time if the leaf compost-treated soils increased a plant's ISR given the methods used in this experiment. Additional research will also need to be conducted in this area to further bolster or refute this claim. Flying fields with unmanned aerial vehicles (UAVs) or drones fitted with hyperspectral cameras could help researchers obtain more accurate assessments of disease severity in tomato fields (Abdulridha et al., 2019). What can be said is that plants grown in compost-treated soils exhibited fewer symptoms of foliar disease and increased growth and vitality when judged visually. Whether a causal relationship exists between the two is beyond the scope of this experiment.

Yields from tomato plants grown in soils incorporated with the leaf mold compost were positively affected from the treatment. In 2019, we observed a 74.6% increase in the number of good fruits and an 87.5% increase in total good plus healthy green fruit weight at harvest on plants grown in the compost amended plots when compared with the unamended controls. The 2020 growing season mirrored these results. There was a 63.1% increase in the number of good fruits and a 49.6% increase in the total weight of good fruits plus healthy green fruits picked during the final harvest. Combining the two years, a 67.7% increase in the total number of good fruits and a 59.3% increase in the total weight of good plus healthy green fruits picked during the final harvest was observed.

How do these yield increases compare to other forms of fertilizer? The optimal amount of synthetic NPK fertilizer for tomato growth is around 223-250 lb/acre before hitting the point of diminishing returns. This amount improves yields by around 30% compared to control plots (Isah et al., 2014). This is less than the observed 56% increase in yield by weight per plant that was observed in our two-season experiment. Treatment with vermicompost, decomposed material from microorganism and worms, has previously been shown to increase tomato yields by 71.7% compared to control soils, and chicken manure compost treatment increased yields by 69.0%

compared to control soils (Wang et al., 2017). These results compare quite similarly to the yield results from our leaf compost experiment.

Compost also has the added advantage over synthetic fertilizers of improving the soil's biogeochemical properties. In fact, indiscriminate use of synthetic fertilizers over the 20th and early 21st century has had detrimental effects on the health of soils worldwide (Gastal and Lemaire, 2002). This is very important because the positive boost in yield from compost has the potential to carry on year-over-year. Synthetic fertilizers leach into the environment quite easily and need to be reapplied annually to maintain yields. Crop yields respond very positively when soil properties are improved. One agronomic study found that improved soil properties accounted for around 40% of yield increases, while synthetic fertilizer accounted for 21% of the increase. Manure accounted for the remaining 39% (Abera et al., 2017). The beneficial effects on yield from a leaf compost incorporated into the soil are profound, but compost alone will most likely not provide the yields needed to sustain future global populations. Research is currently being done to study the effects of compost/synthetic fertilizer hybrid treatments. One study showed a 145% increase in tomato fruit yield when a compost of maize stover, cassava peels and poultry manure was mixed with N from urea (Taiwo et al., 2007).

Our yield results are very promising, especially taking into account the cost, time commitment and positive environmental impact of recycling leaves back into the ground. The agricultural sector is being called upon to increase yields, while decreasing negative environmental impact. This seems like an impossible task at first. On top of that, current tariffs and trade disagreements with China, COVID-19 food chain disruptions, rising input costs and declining future prices are just a few reasons why many producers find themselves in an economic crunch. In fact, 595 American family farmers filed Chapter 12 bankruptcies in 2019: an eight-year high (McCarthy, 2019). USDA estimates show that fertilizer input costs have risen from around \$50 acre^{-1} in the year 2000 to around \$125 acre^{-1} in 2017 (Figure 3.22)

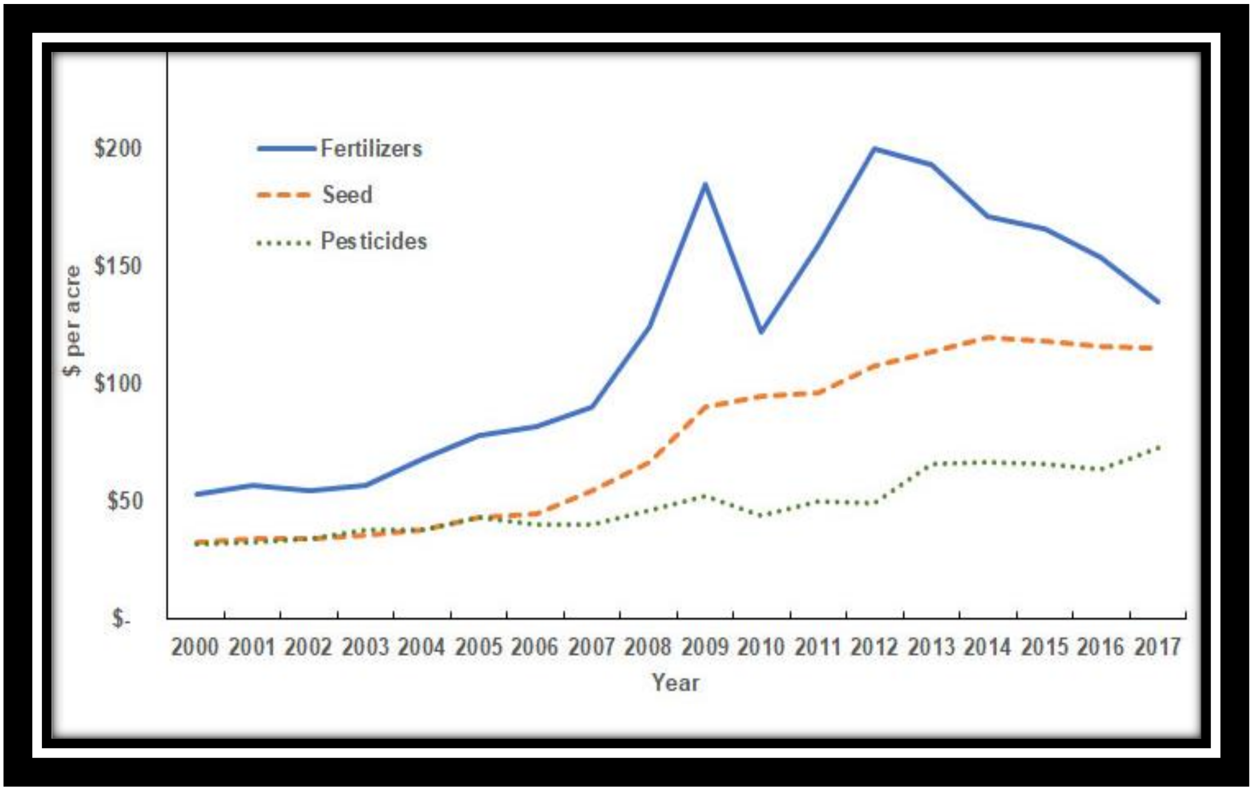


Figure CHAPTER 3.22. Average United States fertilizer, seed and pesticide prices per acre, 2000-2017 (USDA ERS)

The results of this two-year experiment, in conjunction with a growing body of evidence, show that compost treatments have the potential to increase yields without increasing synthetic fertilizer demand. In other words, there is great potential to increase revenue without increasing the cost of inputs. This potential exists while ameliorating poor health of soils, which is a farm's most valuable asset. Smarter, greener solutions such as the utilization of leaf compost on a farming operation can make the difference between survival and bankruptcy for traditional, organic and urban farmers alike.

3.4.2 Trichoderma harzianum T-22 inoculation

Trichoderma survival and effect on yield

The second objective of this trial was to determine if inoculating tomato plants with *T. harzianum* T-22 could further increase the health and productivity of tomato plants. Previous studies conducted under controlled conditions have demonstrated that this fungal isolate can help plants acquire nutrients, withstand abiotic stress and induce systemic resistance to pathogens in tomato (Jaiswal et al., in review).

However, results have been much more variable in the field. This makes it difficult for farmers to rely on these microbes to improve plant growth and help them fight pathogens that cause disease. We aimed to determine if leaf compost amended soils could provide an environment more conducive to fungal growth and thereby increase the survival and activity of this beneficial microbial inoculant in the field. The dramatic increase in survival of tomato plants following transplanting during both years of this trial clearly demonstrate the benefits of inoculating tomato seedlings with this fungus. This could translate into real savings for growers by lowering the costs of transplants and labor associated with replanting dead plants.

We did not observe statistically significant reductions in disease ratings or tomato plant vigor in response to the *T. harzianum* inoculant in either the compost amended or non-amended control treatments. It is interesting to note however, that August SPAD readings during 2019 for control plants were slightly elevated compared to *T. harzianum* inoculated plants, indicating that the introduced fungus could be taking some resources from the plant. We were not able to verify if the compost treatments supported greater survival and proliferation of the fungal inoculant by qPCR as *Trichoderma* levels were too low to be detected. However, analysis from plate trials created from 2020 soil samples provide exciting evidence that compost amended soils fostered an environment more conducive to the abundance and survival of *Trichoderma* organisms. This can be deduced based on the results from Table 3.18. *Trichoderma* inoculations did not lead to significantly increased populations in unamended subplots that were inoculated compared to unamended subplots that were not inoculated. On the flip side, compost amended subplots inoculated with *Trichoderma* did exhibit significantly increased populations compared to amended subplots that were not inoculated. These results were only from one growing season and will need to be replicated to ensure that leaf compost does indeed reduce variability in the survival and abundance of *Trichoderma* organisms in a field setting. With that being said, the results from this experiment are very promising as industry leaders figure out how to increase the efficacy of biotechnologies.

In future trials, researchers should consider planting extra plants that can be destructively harvested to obtain root samples and quantify *T. harzianum* abundance in plant roots since this is where these fungi best thrive and support plants. We did observe a slight yield difference when comparing *T. harzianum* inoculated plants to the non-inoculated control plants. Over the two growing seasons, inoculated plants produced 17.4% more good fruits compared to control plants and 13.6% more good fruits plus healthy green fruits picked during the final harvest by weight when compared to the non-inoculated control plants. However, these results were not statistically significant so this effect cannot be attributed to *T. harzianum* inoculations. Future researchers might consider adding larger volumes of the fungal inoculant in post-transplant treatments to better support this beneficial fungus.

Influence of tomato genotype

Scientists have long known that tomato genotypes or varieties vary in resistance to individual microbial pathogens and therefore selecting for disease resistance has and continues to be an important component of plant breeding programs. In more recent years, scientists have discovered that tomato genotypes also vary in their potential to support beneficial microbes that can help plants acquire resources and withstand biotic and abiotic stress (Tucci et al., 2011l Hoagland et al., 2015; Jaiswal et al., in review). Learning how to leverage these beneficial plant-microbial relationships in tomato breeding programs could provide further benefits to growers and help reduce the need to apply pesticides that can negatively affect the environment. We have previously determined in controlled trials that tomato cv. Corbarino is better able to support and reap the benefits of *T. harzinum* in terms of ISR against two foliar pathogens than cv. Wisconsin 55 (Jaiswal et al., in review). Here we aimed to determine if these differences would hold up in the field, leading to lower disease severity in Wisconsin 55.

2020 seedlings photos provide visual evidence of the beneficial growth effects of *T. harzianum* inoculations and how these results varied by genotype (see Figures 3.15-3.20). We observed dramatic differences in the height and capacity of tomato plants to withstand transplant stress in the field in response to the *T. harzianum* inoculant, but the results were the opposite of what we expected. Both the height at transplanting and ability to survive transplant stress were significantly greater in cv. Wisconsin 55 than Corbarino. While the effect is generally transient, the initial induction of systemic defense responses in tomato plants can represent a cost to the plant as they must relax their defense responses to permit colonization by the beneficial microbial inducer. Consequently, this could be why we observed less of a response in Corbarino in terms of early vigor and capacity to withstand transplant stress. It is also plausible that Wisconsin 55 is weaker during the seedling stage relative to Corbarino, which is supported by our observation of far fewer deaths following transplanting in Corbarino vs. Wisconsin 55. In addition to ISR, *T. harzianum* can also help plants acquire water and nutrients much like AMF, and these benefits are greater in weaker tomato genotypes. Further research to investigate this hypothesis are warranted based on the results of this trial. In the meantime, the results obtained further underscore the benefits growers could receive by inoculating their tomato transplants with this beneficial fungus, regardless of the varieties they plant.

Both Wisconsin 55 and Corbarino varieties tomatoes produced significantly more good fruit when grown in compost amended soils. Composted Wisconsin 55 subplots produced an average of 45% more good fruit, while Corbarino subplots grown in compost produced 71% more good fruit. This effect was also observed for good fruit weights plus the weight of good green fruits picked during the final harvest. In contrast, we observed no significant difference in either variety in response to the *T. harzianum* inoculant, regardless of whether the plants were grown in compost amended or non-amended soils. This would suggest that genotypic differences in *T. harzianum* responsiveness do not carry through in the field. It is interesting to note however, that the increase in tomato yield in response to the compost amendment was greater in Corbarino than Wisconsin 55. Since compost amendments can increase the composition and abundance of soil microbes with disease suppressive activity like *Trichoderma* (Schlatter et al., 2017), it is possible that the greater yield response in Corbarino was due, at least in part, to greater responsiveness to these microbes and a corresponding lower disease severity. However, this assertion would need to be verified in future trials.

3.4.3 Conclusions and Big Picture Impacts

Technological advances during the Green Revolution of the 20th century allowed the human population to rise sharply by increasing global yields of staple crops substantially. These yield improvements are said to have saved a billion lives by providing food for a rapidly increasing global population, especially in lesser developed nations. Modern agricultural scientists face a similar set of circumstances. The global population is expected to rise by an estimated two billion people in the thirty-year window from 2020-2050. Two billion additional mouths to feed presents massive challenges to the global food system. Rising population and urban sprawl in many countries has led to housing and commercial developments on productive peri-urban and rural soils, while climate change is another major variable to be dealt with as it is already negatively impacting global yields of wheat, maize and many other crops worldwide (Global Commission on Adaptation, 2019). If necessity is truly the mother of innovation, agricultural science is on the cusp of major technological advance.

The findings of this two-year experiment provide evidence for the power of green biotechnologies in the fight against global hunger and climate change, particularly in urban settings. The beneficial effects that leaf compost can have on both soil health and tomato yields when it is applied as a soil amendment are very encouraging. The benefits of increasing SOM and microbial survival and diversity are numerous. Improving soil aggregation and water holding capacity are especially important results for producers in dry environments seeking to reduce irrigation needs. P and N are two members of the NPK fertilizer triumvirate of macronutrients that plants need to grow and thrive. Observed increases in soil P and plant tissue N from compost treatments are encouraging results in the effort to decrease the need for synthetic fertilizer application to crops. Combining organic matter's ability to hold soil together and a subsequent decreased need for fertilizer application indicates that leaf compost applications can be a useful method for reducing nutrient runoff that leads to harmful eutrophication of streams, lakes, rivers, gulfs and oceans. Increasing SOM content and nutrient quantity also has the potential to save producers substantial amounts of money by reducing fertilizer cost, reducing nutrient loss from erosion, reducing water inputs and increasing nutrient availability to plants.

Yield improvements of the proportions observed in this trial would be considered very impressive for state-of-the-art technologies created by scientists in multi-million dollar laboratories. Our method of tilling 3-year old composted fallen leaves into the soil is neither state-of-the-art nor a multi-million dollar research creation. The benefits to producers of increasing yields is quite obvious in that it allows farmers to have more product to sell in the marketplace, meaning more income for their families, their savings and next year's expenses. More efficient food production is also a necessary step in the right direction in the Malthusian race against time.

Reducing the occurrence of death from transplant shock due to the *T. harzianum* inoculant is yet another opportunity observed through this research project for producers to save money. Attenuating transplant shock death is very important as this issue has the potential to become a major concern for producers as growing conditions are becoming increasingly harsh for transplants as they acclimate from greenhouse to outdoor fields. In this way, the use of microorganisms like *T. harzianum* as a seedling inoculant may become a necessary practice used by producers to combat climate change as time progresses.

Feeding the growing urban population is going to be an especially tricky endeavor. Urban growth is projected to be the most rapid in low- and lower-middle-income nations (United Nations, 2018). The need for local, community-driven food production sites in these areas is of critical importance to successfully feed everyone. Urban agriculture operations are designed to do just this. These sites are typically small and need to maximize the space they are allotted. Leaf compost amendments can have significant impacts on both yield and overall soil health of urban agriculture operations, thus maximizing urban farm space. *T. harzianum* inoculations also appear to increase efficiency on these operations and our results give preliminary evidence that leaf compost amendments aid in the survival of *Trichoderma* organisms in the field. Improving yields on urban farms greatly increases the chance for residents to gain access to fresh, healthy produce previously unavailable to them. This access can directly aid in the fight against the synergy of epidemics (food insecurity, malnutrition and obesity) that urban residents deal with on a daily basis (Swinburn et al., 2019). Tree leaves are a major source of organic compostable material within city limits, particularly inside of a metropolis. Urban farm managers are encouraged to contact city waste officials and inquire about the fate of fallen leaves collected by the city. Leaves are a potentially free resource with a proven track record. There is nothing to lose by asking, but a slew of benefits to gain.

Suggestions for future research

- Future studies testing the moisture content of leaf compost treated soils against control soil could prove useful data for producers. Leaf compost amendments are touted for their ability to increase a soil's water holding capacity so precise moisture quantification of this variable could be very beneficial for water conservation purposes.
- Future research projects could also measure the residual effects of growing crops year after year on the same experimental plot to see if subsequent years shows similar results. Synthetic fertilizer applications are required annually, but large sums of money could be saved if experimental data can show residual benefits of leaf compost.

- Our two-year experiment shows that treating subplots with a leaf compost increased yields significantly. This is no doubt a positive result in the ongoing battle to feed a growing global population. However, discovering methods of increasing yields only fulfills one of the two major requirements that are placed on modern agricultural scientists and producers. Modern day success in agriculture requires an increase in output while also decreasing negative environmental impacts. Future studies should be undertaken to dig deeper into year-after-year environmental impacts of amending soils with leaf compost. Questions to investigate include, but are not limited to: Do leaf compost amended soils decrease the risk of nutrient leaching? Do leaf composted soils significantly reduce the need to irrigate? What are long-term C sequestration impacts when comparing control soils to soils amended with leaf compost?
- Decreased SPAD readings for *T. harzianum* treated plants in August of 2019 and 2020 raises an interesting question concerning the efficacy of biological control agents. Is there a possibility that symbiotic *T. harzianum* organisms are a resource sink that are utilizing nutrients that the plant would otherwise have taken up? Further research could be done to investigate whether inoculation with *T. harzianum* communities deprive nutrients from the roots in which they colonize.
- Significant differences for various soil tests were observed in 2019 tests, but not for 2020 tests. This may be due to more compost added incorporated into the soil in the 2019 season compared to the 2020 season. Future research investigating the effects of various amounts of leaf compost incorporated into the soil could prove very useful for discovering a recommended amount.
- Discussing whether or not compost treatments significantly affected *T. harzianum* population growth and abundance in the root zone of tomato plants cannot be accomplished using qPCR results. qPCR results were unable to be attained due to population levels of *T. harzianum* too small for the machinery to detect. Better methods for quantifying *T. harzianum* in soils are needed as are studies that collect plant roots.
- *T. harzianum* inoculations significantly reduced transplant shock deaths of Wisconsin 55 but not Corbarino variety plants. Future research that pinpoints phenotypic discrepancies between genotypes is necessary to ensure optimum efficiency of microbial inoculation treatments.

- Many results throughout this research project yielded insignificant results. There does, however, seem to be a trend when analyzing these insignificant results. Compost treated plots tested 27.2% higher in K levels, 9.2% in Mg levels, 9.2% in Ca levels and 10.3% in cation exchange capacity (CEC). Compost treated subplots also exhibited a 30% increase in the average amount of NO_3- + NO_2- and a 15% increase in the average amount of NH_3 compared to control soils. These results indicate that further research in this area is needed to validate whether these results were due to chance or if they are replicable in commercial settings.

3.5 References

2020 Global Nutrition Report | Executive summary - Global Nutrition Report. (2020). Action on Equity to End Malnutrition. Retrieved September 16, 2020, from https://globalnutritionreport.org/reports/2020-global-nutrition-report/executive-summary/

Abdel-Kader, M. M., Abdel-Kareem, F., El-Mougy, N. S., & El-Mohamady, R. S. (2013). Integration between Compost, Trichoderma harzianum and Essential Oils for Controlling Peanut Crown Rot under Field Conditions. *Journal of Mycology*, *2013*, 1–7. https://doi.org/10.1155/2013/262130

Abdulridha, J., Ampatzidis, Y., Kakarla, S. C., & Roberts, P. (2019). Detection of target spot and bacterial spot diseases in tomato using UAV-based and benchtop-based hyperspectral imaging techniques. *Precision Agriculture*, *21*(5), 955–978. https://doi.org/10.1007/s11119-019-09703-4

Abera, T., Debele, T., & Wegary, D. (2017). Effects of Varieties and Nitrogen Fertilizer on Yield and Yield Components of Maize on Farmers Field in Mid Altitude Areas of Western Ethiopia. *International Journal of Agronomy*, *2017*, 1–13. https://doi.org/10.1155/2017/4253917

Akratos, C.S., Tekerlekopoulou, A.G., Vasiliadou, I.A., and Vayenas, D.V. (2017). Evaluation of alperujo composting based on organic matter degradation, humification and compost quality. *Biodegradation* 20, 257.

Aktar, W., Sengupta, D., & Chowdhury, A. (2009). Impact of pesticides use in agriculture: their benefits and hazards. *Interdisciplinary Toxicology*, *2*(1), 1–12. https://doi.org/10.2478/v10102-009-0001-7

Alaimo, K., Packnett, E., Miles, R. A., & Kruger, D. J. (2008). Fruit and Vegetable Intake among Urban Community Gardeners. *Journal of Nutrition Education and Behavior*, *40*(2), 94–101. https://doi.org/10.1016/j.jneb.2006.12.003

Al-Kaisi, M. (2002, March 18). *Do I need to till my soil? | Integrated Crop Management*. Iowa State University Extension and Outreach. https://crops.extension.iastate.edu/encyclopedia/do-i-need-till-my-soil

Alonso-Ramírez, A., Poveda, J., Martín, I., Hermosa, R., Monte, E., & Nicolás, C. (2014). Salicylic acid preventsTrichoderma harzianumfrom entering the vascular system of roots. *Molecular Plant Pathology*, *15*(8), 823–831. https://doi.org/10.1111/mpp.12141

Asmelash F, Bekele T and Birhane E. (2016) The Potential Role of Arbuscular Mycorrhizal Fungi in the Restoration of Degraded Lands. Front. *Frontiers in Microbiology*. 7:1095. doi: 10.3389/fmicb.2016.01095

Asrar, A. (2011). The Role of Arbuscular Mycorrhiza in Protection of Kalanchoe Blossfeldiana Plants Against Heavy Metal Toxicity in Sewage Water Contaminated Soil. *Journal of Plant Production*, *2*(8), 1047–1060. https://doi.org/10.21608/jpp.2011.85636

Battersby, J. (2011). Urban food insecurity in Cape Town, South Africa: An alternative approach to food access. *Development Southern Africa*, *28*(4), 545–561. https://doi.org/10.1080/0376835x.2011.605572

Beach, R. H., Sulser, T. B., Crimmins, A., Cenacchi, N., Cole, J., Fukagawa, N. K., Mason-D'Croz, D., Myers, S., Sarofim, M. C., Smith, M., & Ziska, L. H. (2019). Combining the effects of increased atmospheric carbon dioxide on protein, iron, and zinc availability and projected climate change on global diets: a modelling study. *The Lancet Planetary Health*, *3*(7), e307–e317. https://doi.org/10.1016/s2542-5196(19)30094-4

Begum N, Qin C, Ahanger MA, Raza S, Khan MI, Ashraf M, Ahmed N and Zhang L (2019) Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. *Front. Plant Sci*. 10:1068. doi: 10.3389/fpls.2019.01068

Behie, S. W., & Bidochka, M. J. (2013). Ubiquity of Insect-Derived Nitrogen Transfer to Plants by Endophytic Insect-Pathogenic Fungi: an Additional Branch of the Soil Nitrogen Cycle. *Applied and Environmental Microbiology*, *80*(5), 1553–1560. https://doi.org/10.1128/aem.03338-13

Bell, J. E., Herring, S. C., Jantarasami, L., Adrianopoli, C., Benedict, K., Conlon, K., Escobar, V., Hess, J., Luvall, J., Garcia-Pando, C. P., Quattrochi, D., Runkle, J., & Schreck, C. J. (2016). Ch. 4: Impacts of Extreme Events on Human Health. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. *U.S. Global Change Research Program*, 99–128. https://doi.org/10.7930/j0bz63zv

Bhattacharyya, P. N., & Jha, D. K. (2011). Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. *World Journal of Microbiology and Biotechnology*, *28*(4), 1327–1350. https://doi.org/10.1007/s11274-011-0979-9

Bianchi, F., Booij, C. & Tscharntke, T. (2006). Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proceedings of the Royal Society 273: 1715-1727.

Birhane, E., Sterck, F. J., Fetene, M., Bongers, F., & Kuyper, T. W. (2012). Arbuscular mycorrhizal fungi enhance photosynthesis, water use efficiency, and growth of frankincense seedlings under pulsed water availability conditions. *Oecologia*, *169*(4), 895–904. https://doi.org/10.1007/s00442-012-2258-3

Bitterlich, M., Rouphael, Y., Graefe, J., & Franken, P. (2018). Arbuscular Mycorrhizas: A Promising Component of Plant Production Systems Provided Favorable Conditions for Their Growth. *Frontiers in Plant Science*, *9*, 1–6. https://doi.org/10.3389/fpls.2018.01329

Bock, C. H., Barbedo, J. G. A., Del Ponte, E. M., Bohnenkamp, D., & Mahlein, A.-K. (2020). From visual estimates to fully automated sensor-based measurements of plant disease severity: status and challenges for improving accuracy. *Phytopathology Research*, *2*(1), 9. https://doi.org/10.1186/s42483-020-00049-8

Bonanomi, G., Lorito, M., Vinale, F., & Woo, S. L. (2018). Organic Amendments, Beneficial Microbes, and Soil Microbiota: Toward a Unified Framework for Disease Suppression. *Annual Review of Phytopathology*, *56*(1), 1–20. https://doi.org/10.1146/annurev-phyto-080615-100046

Bonneville, M., & Fyles, J. W. (2006). Assessing Variations in SPAD-502 Chlorophyll Meter Measurements and Their Relationships with Nutrient Content of Trembling Aspen Foliage. *Communications in Soil Science and Plant Analysis*, *37*(3–4), 525–539. https://doi.org/10.1080/00103620500449385

Boonyabancha, S., Kerr, T., Joshi, L., & Tacoli, C. (2019). How the urban poor define and measure food security in Cambodia and Nepal. *Environment and Urbanization*, *31*(2), 517–532. https://doi.org/10.1177/0956247819863246

Brady, N. C., & Weil, R. R. (2009). *Elements of the Nature and Properties of Soils (3rd Edition)* (3rd ed.). Pearson.

Brunius, G. (1980). Technical aspects of the use of 3′,6′-diacetyl fluorescein for vital fluorescent staining of bacteria. *Current Microbiology*, *4*(6), 321–323. https://doi.org/10.1007/bf02605370

Brust, G. E. (2019). Management Strategies for Organic Vegetable Fertility. *Safety and Practice for Organic Food*, 193–212. https://doi.org/10.1016/b978-0-12-812060-6.00009-x

Busari, M. A., Kukal, S. S., Kaur, A., Bhatt, R., & Dulazi, A. A. (2015). Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research*, *3*(2), 119–129. https://doi.org/10.1016/j.iswcr.2015.05.002

Calderón, F. J., Culman, S., Six, J., Franzluebbers, A. J., Schipanski, M., Beniston, J., Grandy, S., & Kong, A. Y. Y. (2017). Quantification of Soil Permanganate Oxidizable C (POXC) Using Infrared Spectroscopy. *Soil Science Society of America Journal*, *81*(2), 277–288. https://doi.org/10.2136/sssaj2016.07.0216

Cappucci, M. (2020, August 13). Midwest derecho devastates Iowa corn crop. Satellite imagery shows damage. *Washington Post.* Retrieved from https://www.washingtonpost.com/

Center on Budget and Policy Priorities. (2020, September 16). *States Are Using Much-Needed Temporary Flexibility in SNAP to Respond*. Retrieved September 16, 2020, from https://www.cbpp.org/research/food-assistance/states-are-using-much-needed-temporary-flexibility-in-snap-to-respond-to

Cleemput, O., & Samater, A. H. (1995). Nitrite in soils: accumulation and role in the formation of gaseous N compounds. *Fertilizer Research*, *45*(1), 81–89. https://doi.org/10.1007/bf00749884

Cook, R. j., Bruckart, W. L., Coulson, J. R., Goettel, M. S., Humber, R. A., Lumsden, R. D., Maddox, J. V., McManus, M. L., Moore, L., Meyer, S. F., Quimby, Jr., P. C., Stack, J. P., & Vaughn, J. L. (1996). Safety of Microorganisms Intended for Pest and Plant Disease Control: A Framework for Scientific Evaluation. *Biological Control*, *7*(3), 333–351. https://doi.org/10.1006/bcon.1996.0102

Coppola, M., Cascone, P., Chiusano, M. L., Colantuono, C., Lorito, M., Pennacchio, F., Rao, R., Woo, S. L., Guerrieri, E., & Digilio, M. C. (2017). Trichoderma harzianum enhances tomato indirect defense against aphids. *Insect Science*, *24*(6), 1025–1033. https://doi.org/10.1111/1744-7917.12475

Cordo, C. A., Monaco, C. I., Segarra, C. I., Simon, M. R., Mansilla, A. Y., Perelló, A. E., Kripelz, N. I., Bayo, D., & Conde, R. D. (2007). Trichodermaspp. as elicitors of wheat plant defense responses against Septoria tritici. *Biocontrol Science and Technology, 17*(7), 687–698. https://doi.org/10.1080/09583150701527094

Cornelissen, J. H. C., Sibma, F., Van Logtestijn, R. S. P., Broekman, R. A., & Thompson, K. (2010). Leaf pH as a plant trait: species-driven rather than soil-driven variation. *Functional Ecology*, *25*(3), 449–455. https://doi.org/10.1111/j.1365-2435.2010.01765.x

Cornell University. (n.d.). Agronomy Fact Sheet Series [Soil Organic Matter]. New York, Ithaca, NY.

Costa, L. G. (2008). Neurotoxicity of pesticides: a brief review. *Frontiers in Bioscience*, *13*(13), 1240. https://doi.org/10.2741/2758

De Kimpe, C. R., & Morel, J.-L. (2000). Urban Soil Management. A Modern Concern. *Soil Science*, *165*(1), 31–40. https://doi.org/10.1097/00010694-200001000-00005

Debbi, A., Boureghda, H., Monte, E., & Hermosa, R. (2018). Distribution and Genetic Variability of Fusarium oxysporum Associated with Tomato Diseases in Algeria and a Biocontrol Strategy with Indigenous Trichoderma spp. *Frontiers in Microbiology*, *9*, 1–11. https://doi.org/10.3389/fmicb.2018.00282

Drewnowski, A. (2012). The Economics of Food Choice Behavior: Why Poverty and Obesity Are Linked. *Obesity Treatment and Prevention: New Directions*, 95–112. https://doi.org/10.1159/000341303

Druzhinina, I. S., Chenthamara, K., Zhang, J., Atanasova, L., Yang, D., Miao, Y., Rahimi, M. J., Grujic, M., Cai, F., Pourmehdi, S., Salim, K. A., Pretzer, C., Kopchinskiy, A. G., Henrissat, B., Kuo, A., Hundley, H., Wang, M., Aerts, A., Salamov, A., … Kubicek, C. P. (2018). Massive lateral transfer of genes encoding plant cell wall-degrading enzymes to the mycoparasitic fungus Trichoderma from its plant-associated hosts. *PLOS Genetics*, *14*(4), e1007322. https://doi.org/10.1371/journal.pgen.1007322

Druzhinina, I. S., Seidl-Seiboth, V., Herrera-Estrella, A., Horwitz, B. A., Kenerley, C. M., Monte, E., Mukherjee, P. K., Zeilinger, S., Grigoriev, I. V., & Kubicek, C. P. (2011). Trichoderma: the genomics of opportunistic success. *Nature Reviews Microbiology*, *9*(10), 749–759. https://doi.org/10.1038/nrmicro2637

Dubey, A., Malla, M. A., Khan, F., Chowdhary, K., Yadav, S., Kumar, A., Sharma, S., Khare, P. K., & Khan, M. L. (2019). Soil microbiome: a key player for conservation of soil health under changing climate. *Biodiversity and Conservation*, *28*(8–9), 2405–2429. https://doi.org/10.1007/s10531-019-01760-5

Elsharkawy, M. M., Shimizu, M., Takahashi, H., Ozaki, K., & Hyakumachi, M. (2013). Induction of Systemic Resistance against Cucumber mosaic virus in Arabidopsis thaliana by Trichoderma asperellum SKT-1. *The Plant Pathology Journal*, *29*(2), 193–200. https://doi.org/10.5423/ppj.si.07.2012.0117

Environmental Protection Agency. (2020, September 10). *Global Greenhouse Gas Emissions Data*. US EPA. Retrieved on September 16, 2020, from https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

Eswaran, H., Lal, R., & Reich, P. F. (2019). Land degradation: An overview. *Response to Land Degradation*, 20–35. https://doi.org/10.1201/9780429187957-4

FAO (2016, November 30). Building greener cities: Nine benefits of urban trees. Retrieved July 22, 2020, from http://www.fao.org/zhc/detail-events/en/c/454543/

FAO. (2015). *Status of the World's Soil Resources*. FAO. Retreived on September 16, 2020, from http://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/

Feeding America. (2020, April 8). Feeding America Network Faces Soaring Demand, Plummeting Supply Due to COVID-19 Crisis. Retrieved September 16, 2020, from https://www.feedingamerica.org/about-us/press-room/soaring-demand-plummeting-supply

Ferreira, H., & Ferreira Filho, E. (2004). Purification and characterization of a β-mannanase from Trichoderma harzianum strain T4. *Carbohydrate Polymers*, *57*(1), 23–29. https://doi.org/10.1016/j.carbpol.2004.02.010

Fierer, N., & Jackson, R. B. (2006). The diversity and biogeography of soil bacterial communities. *Proceedings of the National Academy of Sciences*, *103*(3), 626–631. https://doi.org/10.1073/pnas.0507535103

Food and Agriculture Organization of the United Nations. (2019). The State of Food Security and Nutrition in the World 2019: Safeguarding against economic slowdowns and downturns. (2019 Edition). Retrieved September 16, 2020, from https://docs.wfp.org/api/documents/WFP-0000106760/download/?_ga=2.122074059.1932717538.1600256701-250291572.1600256701

Funderburg, E. E. (2001, July 31). *What Does Organic Matter Do In Soil?* Noble Research Institute. https://www.noble.org/news/publications/ag-news-and-views/2001/august/what-does-organic-matter-do-in-soil/

Gastal, F., & Lemaire, G. (2002). N uptake and distribution in crops: an agronomical and ecophysiological perspective. *Journal of Experimental Botany*, *53*(370), 789–799. https://doi.org/10.1093/jexbot/53.370.789

Gautheret, A., Dromer, F., Bourhis, J.-H., & Andremont, A. (1995). Trichoderma pseudokoningii as a Cause of Fatal Infection in a Bone Marrow Transplant Recipient. *Clinical Infectious Diseases*, *20*(4), 1063–1064. https://doi.org/10.1093/clinids/20.4.1063

Gershuny, G., & Martin, D. L. (2018). The Rodale book of composting: Simple methods to improve your soil, recycle waste, grow healthier plants, and create an earth-friendly garden. New York, NY: Rodale Books.

Global Commission on Adaptation. (2019, September). *Adapt Now: A Global Call for Leadership on Climat Resilience*. https://cdn.gca.org/assets/2019-09/GlobalCommission_Report_FINAL.pdf

Gloy, B. A., Boehlje, M, & Widmar, D. A. (2015) The Great Margin Squeeze: Strategies for Managing Through the Cycle. Purdue University Center for Commercial Agriculture. Retrieved on September 16, 2020, from https://ag.purdue.edu/commercialag/home/resource/2015/01/the-great-margin-squeeze-strategies-for-managing-through-the-cycle/

Greater Victoria Compost Education Centre. (n.d.). *Fact Sheet Series: Urban Leaves*. Canada, Victoria, British Columbia. https://compost.bc.ca/wp-content/uploads/2015/02/FactSheet-6-Urban-Leaves_Revised-Feb-2015.pdf

Haddaway, N. R., Hedlund, K., Jackson, L. E., Kätterer, T., Lugato, E., Thomsen, I. K., Jørgensen, H. B., & Isberg, P.-E. (2016). How does tillage intensity affect soil organic carbon? A systematic review protocol. *Environmental Evidence, 5*(1), 6. https://doi.org/10.1186/s13750-016-0052-0

Harman, G. E. (2000). Myths and Dogmas of Biocontrol Changes in Perceptions Derived from Research on Trichoderma harzinum T-22. *Plant Disease, 84*(4), 377–393. https://doi.org/10.1094/pdis.2000.84.4.377

Harman, G. E. (2006). Overview of Mechanisms and Uses of Trichoderma spp. *Phytopathology®, 96*(2), 190–194. https://doi.org/10.1094/phyto-96-0190

Harman, G. E., Howell, C. R., Viterbo, A., Chet, I., & Lorito, M. (2004). Trichoderma species — opportunistic, avirulent plant symbionts. *Nature Reviews Microbiology*, *2*(1), 43–56. https://doi.org/10.1038/nrmicro797

Hartmann, A., & Schikora, A. (2012). Quorum Sensing of Bacteria and Trans-Kingdom Interactions of N-Acyl Homoserine Lactones with Eukaryotes. *Journal of Chemical Ecology, 38*(6), 704–713. https://doi.org/10.1007/s10886-012-0141-7Hatfield, J. L., Boote, K. J., Kimball, B. A., Ziska, L. H., Izaurralde, R. C., Ort, D., Thomson, A. M., & Wolfe, D. (2011). Climate Impacts on Agriculture: Implications for Crop Production. *Agronomy Journal*, *103*(2), 351–370. https://doi.org/10.2134/agronj2010.0303

Hawkins, N. J., Bass, C., Dixon, A., & Neve, P. (2018). The evolutionary origins of pesticide resistance. *Biological Reviews*, *94*(1), 135–155. https://doi.org/10.1111/brv.12440

Herman, G. E. (n.d.). *Trichoderma*. Cornell University College of Agriculture and Life Sciences. Retrieved September 16, 2020, from https://biocontrol.entomology.cornell.edu/pathogens/trichoderma.php

Hesterman, O., & Horan, D. (2017, April 25). *The demand for "local" food is growing — here's why investors should pay attention*. Business Insider. https://www.businessinsider.com/the-demand-for-local-food-is-growing-2017-4?international=true&r=US&IR=T

Hiltner L. (1904). Uber neuere Erfahrungen und Probleme auf dem Gebiete der Bodenbakteriologie unter besonderden berucksichtigung und Brache. *Arb. Dtsch. Landwirtsch. Gesellschaft* 98 59–78

Hoagland, L., Carpenter-Boggs, L., Granatstein, D., Mazzola, M., Smith, J., Peryea, F., & Reganold, J. P. (2008). Orchard floor management effects on nitrogen fertility and soil biological activity in a newly established organic apple orchard. Biology and Fertility of Soils, 45(1), 11–18. https://doi.org/10.1007/s00374-008-0304-4

Hoagland, L., Navazio, J., Zystro, J., Kaplan, I., Vargas, J. G., & Gibson, K. (2015). Key Traits and Promising Germplasm for an Organic Participatory Tomato Breeding Program in the U.S. Midwest. *HortScience*, *50*(9), 1301–1308. https://doi.org/10.21273/hortsci.50.9.1301

Högberg, M. N., Högberg, P., & Myrold, D. D. (2006). Is microbial community composition in boreal forest soils determined by pH, C-to-N ratio, the trees, or all three? *Oecologia*, *150*(4), 590–601. https://doi.org/10.1007/s00442-006-0562-5

Hoorman, J. (2016, June 7). *Role of Soil Fungus*. Ohio State University Extension. Retrieved September 16, 2020, from https://ohioline.osu.edu/factsheet/anr-37

Hoorman, J., & Islam, R. (2010, September 7). *Understanding Soil Microbes and Nutrient Recycling*. Ohioline. Retrieved on September 16, 2020, from https://ohioline.osu.edu/factsheet/SAG-16

Horsfall J. G. & Barratt R. W. (1945) An Improved Grading System for Measuring Plant Diseases. *Phytopathology* 35:655.

Huizar, M. I., Arena, R., & Laddu, D. R. (2020). The global food syndemic: The impact of food insecurity, Malnutrition and obesity on the healthspan amid the COVID-19 pandemic. *Progress in Cardiovascular Diseases*, 1–3. https://doi.org/10.1016/j.pcad.2020.07.002

Iowa State University Extension. (n.d.). *Phosphorus deficiency - Vegetables | University of Maryland Extension*. Phosphorous Deficiency - Vegetables. Retrieved September 19, 2020, from https://extension.umd.edu/hgic/topics/phosphorus-deficiency-vegetables

Isah, A. S., Amans, E. B., Odion, E. C., & Yusuf, A. A. (2014). Growth Rate and Yield of Two Tomato Varieties (Lycopersicon esculentumMill) under Green Manure and NPK Fertilizer Rate Samaru Northern Guinea Savanna. *International Journal of Agronomy*, *2014*, 1–8. https://doi.org/10.1155/2014/932759

Jeger, M. J., & Viljanen-Rollinson, S. L. H. (2001). The use of the area under the disease-progress curve (AUDPC) to assess quantitative disease resistance in crop cultivars. *Theoretical and Applied Genetics*, *102*(1), 32–40. https://doi.org/10.1007/s001220051615

Jie, C., Jing-zhang, C., Man-zhi, T., & Zi-tong, G. (2002). Soil degradation: a global problem endangering sustainable development. *Journal of Geographical Sciences*, *12*(2), 243–252. https://doi.org/10.1007/bf02837480

Johns Hopkins Center for a Livable Future. (n.d.) A Guide to Testing Soil for Heavy Metals. Retrieved on September 17, 2020, from https://clf.jhsph.edu/sites/default/files/2019-03/suh-soil-testing-guide-2019.pdf

Kalia, A., & Gosal, S. K. (2011). Effect of pesticide application on soil microorganisms. *Archives of Agronomy and Soil Science*, *57*(6), 569–596. https://doi.org/10.1080/03650341003787582

Karnik, A., Foster, B. A., Mayer, V., Pratomo, V., McKee, D., Maher, S., Campos, G., & Anderson, M. (2011). Food Insecurity and Obesity in New York City Primary Care Clinics. Medical Care, 49(7), 658–661. https://doi.org/10.1097/mlr.0b013e31820fb967

Kleifeld, O., & Chet, I. (1992). Trichoderma harzianum?interaction with plants and effect on growth response. *Plant and Soil*, *144*(2), 267–272. https://doi.org/10.1007/bf00012884

Kole, R. K., Banerjee, H., & Bhattacharyya, A. (2001). Monitoring of Market Fish Samples for Endosulfan and Hexachlorocyclohexane Residues in and Around Calcutta. *Bulletin of Environmental Contamination and Toxicology*, *67*(4), 554–559. https://doi.org/10.1007/s001280159

Kopittke, P. M., Menzies, N. W., Wang, P., McKenna, B. A., & Lombi, E. (2019). Soil and the intensification of agriculture for global food security. *Environment International*, *132*, 105078. https://doi.org/10.1016/j.envint.2019.105078

Korob, S. (2018, May 23). *Role of Phosphorus in Tomato Production*. Yara United States. Retrieved on September 19, 2020, from https://www.yara.us/crop-nutrition/tomato/role-of-phosphorus/

Korob, S. (2018, May 23 b). *Role of Sulfur in Tomato Production*. Yara United States. Retrieved on September 19, 2020, from https://www.yara.us/crop-nutrition/tomato/role-of-sulfur/

Kralik P and Ricchi M. (2017). A Basic Guide to Real Time PCR in Microbial Diagnostics: Definitions, Parameters, and Everything. Front. Microbiol. 8:108. Doi: 10.3389/fmicb.2017.00108

Kremer, R. J., & Means, N. E. (2009). Glyphosate and glyphosate-resistant crop interactions with rhizosphere microorganisms. *European Journal of Agronomy*, *31*(3), 153–161. https://doi.org/10.1016/j.eja.2009.06.004

Lassaletta, L., Billen, G., Grizzetti, B., Anglade, J., & Garnier, J. (2014). 50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland. *Environmental Research Letters*, *9*(10), 105011. https://doi.org/10.1088/1748-9326/9/10/105011

Lee-Smith, D. (2010). Cities feeding people: an update on urban agriculture in equatorial Africa. Environment and Urbanization, 22(2), 483–499. https://doi.org/10.1177/0956247810377383

Lindsey, R., & Dahlman, L. (2020, August 14). *Climate Change: Global Temperature | NOAA Climate.gov*. Climate.Gov. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

Lobell, D. B. (2013). The use of satellite data for crop yield gap analysis. *Field Crops Research*, *143*, 56–64. https://doi.org/10.1016/j.fcr.2012.08.008

Lu, Y., Song, S., Wang, R., Liu, Z., Meng, J., Sweetman, A. J., Jenkins, A., Ferrier, R. C., Li, H., Luo, W., & Wang, T. (2015). Impacts of soil and water pollution on food safety and health risks in China. *Environment International*, *77*, 5–15. https://doi.org/10.1016/j.envint.2014.12.010

Lundgren, B., & Lundgren, B. (1981). Fluorescein Diacetate as a Stain of Metabolically Active Bacteria in Soil. *Oikos*, *36*(1), 17. https://doi.org/10.2307/3544373

MacDonald, G. M. (2010). Water, climate change, and sustainability in the southwest. *Proceedings of the National Academy of Sciences*, *107*(50), 21256–21262. https://doi.org/10.1073/pnas.0909651107

Maček, I., Clark, D. R., Šibanc, N., Moser, G., Vodnik, D., Müller, C., & Dumbrell, A. J. (2019). Impacts of long-term elevated atmospheric CO 2 concentrations on communities of arbuscular mycorrhizal fungi. *Molecular Ecology*, 3445–3458. https://doi.org/10.1111/mec.15160

Mahal NK, Osterholz WR, Miguez FE, Poffenbarger HJ, Sawyer JE, Olk DC, Archontoulis SV and Castellano MJ (2019) Nitrogen Fertilizer Suppresses Mineralization of Soil Organic Matter in Maize Agroecosystems. *Front. Ecol. Evol*. 7:59. doi: 10.3389/fevo.2019.00059

Maino, J. L., Umina, P. A., & Hoffmann, A. A. (2017). Climate contributes to the evolution of pesticide resistance. *Global Ecology and Biogeography*, *27*(2), 223–232. https://doi.org/10.1111/geb.12692

Mallakpour, I., & Villarini, G. (2015). The changing nature of flooding across the central United States. *Nature Climate Change*, *5*(3), 250–254. https://doi.org/10.1038/nclimate2516

Marais, A., Hardy, M., Booyse, M., & Botha, A. (2012). Effects of Monoculture, Crop Rotation, and Soil Moisture Content on Selected Soil Physicochemical and Microbial Parameters in Wheat Fields. *Applied and Environmental Soil Science*, *2012*, 1–13. https://doi.org/10.1155/2012/593623

Martínez-Medina, A., Fernandez, I., Lok, G. B., Pozo, M. J., Pieterse, C. M. J., & Van Wees, S. C. M. (2016). Shifting from priming of salicylic acid- to jasmonic acid-regulated defences byTrichodermaprotects tomato against the root knot nematodeMeloidogyne incognita. *New Phytologist*, *213*(3), 1363–1377. https://doi.org/10.1111/nph.14251

Martinez-Medina, A., Flors, V., Heil, M., Mauch-Mani, B., Pieterse, C. M. J., Pozo, M. J., Ton, J., van Dam, N. M., & Conrath, U. (2016). Recognizing Plant Defense Priming. *Trends in Plant Science*, *21*(10), 818–822. https://doi.org/10.1016/j.tplants.2016.07.009

Maxwell, D., Levin, C., & Csete, J. (1998). Does urban agriculture help prevent malnutrition? Evidence from Kampala. Food Policy, 23(5), 411–424. https://doi.org/10.1016/s0306-9192(98)00047-5

Maynard, A. A., &; Hill, D. E. (2000). Cumulative Effect of Leaf Compost on Yield And Size Distribution in Onions. Compost Science &; Utilization, 8(1), 12-18. doi:10.1080/1065657x.2000.10701744

McBratney, A. B., Morgan, C. L. S., & Jarrett, L. E. (2017). The Value of Soil's Contributions to Ecosystem Services. *Progress in Soil Science*, 227–235. https://doi.org/10.1007/978-3-319-43394-3_20

McCarthy, N. (2020 Feb 10) *Forbes Magazine*. Retrieved on September 19, 2020, from https://www.forbes.com/sites/niallmccarthy/2020/02/10/us-farm-bankruptcies-reach-eight-year-high-infographic/#3e35d31f7de0

Meena, R., Kumar, S., Datta, R., Lal, R., Vijayakumar, V., Brtnicky, M., Sharma, M., Yadav, G., Jhariya, M., Jangir, C., Pathan, S., Dokulilova, T., Pecina, V., & Marfo, T. (2020). Impact of Agrochemicals on Soil Microbiota and Management: A Review. *Land*, *9*(2), 34. https://doi.org/10.3390/land9020034

Milosevic, N., & Govedarica, M. (2002). Effect of herbicides on microbiological properties of soil. *Zbornik Matice Srpske Za Prirodne Nauke*, *102*, 5–21. https://doi.org/10.2298/zmspn0201005m

Miyao G, Goodell PB, Davis RM, Hembree KJ, Natwick ET, Ploeg A, Aegerter BJ, Lanini WT, Stapleton JJ, Stoddard CS, Subbarao KV, Trumble JT, Zalom FG. (2013 December). *UC IPM Pest Management Guidelines: Tomato*. UC ANR Publication 3470. Oakland, CA.

Moe, L. A. (2013). Amino acids in the rhizosphere: From plants to microbes. *American Journal of Botany*, *100*(9), 1692–1705. https://doi.org/10.3732/ajb.1300033

Naikwade, P. (2014). Effect of litter compost on yield and nutrient content of Zea Mays L. *Sci. Res* Rep. 4(1):79–84

Nathan, M. (2016, July 15). *Diagnosing Nutrient Deficiencies (Manjula Nathan)*. Diagnosing Nutrient Deficiencies. Retrieved September 19, 2020, from https://ipm.missouri.edu/IPCM/2016/7/Diagnosing_Nutrient_Deficiencies/

Nicot, P. (2011) Classical and augmentative biological control against diseases and pests: critical status analysis and review of factors influencing their success. *IOBC - International Organisation for Biological and Integrated Control of Noxious Animals and Plants*, 194 p., 2011, 978-92-9067-243-2.

Nieto-Jacobo, M. F., Steyaert, J. M., Salazar-Badillo, F. B., Nguyen, D. V., Rostás, M., Braithwaite, M., De Souza, J. T., Jimenez-Bremont, J. F., Ohkura, M., Stewart, A., & Mendoza-Mendoza, A. (2017). Environmental Growth Conditions of Trichoderma spp. Affects Indole Acetic Acid Derivatives, Volatile Organic Compounds, and Plant Growth Promotion. *Frontiers in Plant Science*, *8*, 1–18. https://doi.org/10.3389/fpls.2017.00102

Noel, S., Mikulcak, F., Etter, H., Stewart, N. (2015 June 15). Economics of Land Degradation Initiative: Report for policy and decision makers. Reaping economic and environmental benefits from sustainable land management. Bonn, Germany: ELD Initiative and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Nogueira-Lopez G, Greenwood DR, Middleditch M, Winefield C, Eaton C, Steyaert JM and Mendoza-Mendoza A (2018) The Apoplastic Secretome of Trichoderma virens During Interaction With Maize Roots Shows an Inhibition of Plant Defence and Scavenging Oxidative Stress Secreted Proteins. Front. Plant Sci. 9:409. doi: 10.3389/fpls.2018.00409

Ochoa-Hueso R (2017) Global Change and the Soil Microbiome: A Human-Health Perspective. Front. Ecol. Evol. 5:71. doi: 10.3389/fevo.2017.00071

Oregon State University Extension. (2019, August). *Soil organic matter as a soil health indicator: Sampling, testing, and interpretation*. Retrieved on September 19, 2020, from https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em9251.pdf

Patnaik, G.K., Kanungo, P.K., Adhya, T.K. and Rao, V.R. (1996). Effect of repeated applications of gammahexachlorocyclohexane (gamma-HCH) on nitrogenase activity and nitrogen-fixing bacteria associated with rhizosphere of tropical rice. Microbiol. Res., 151:375–378

Peng, S., Huang, J., Sheehy, J. E., Laza, R. C., Visperas, R. M., Zhong, X., Centeno, G. S., Khush, G. S., & Cassman, K. G. (2004). Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Sciences*, *101*(27), 9971–9975. https://doi.org/10.1073/pnas.0403720101

Penton, C. R., Gupta, V. V. S. R., Tiedje, J. M., Neate, S. M., Ophel-Keller, K., Gillings, M., Harvey, P., Pham, A., & Roget, D. K. (2014). Fungal Community Structure in Disease Suppressive Soils Assessed by 28S LSU Gene Sequencing. *PLoS ONE*, *9*(4), e93893. https://doi.org/10.1371/journal.pone.0093893

Pingali, P. L. (2012). Green Revolution: Impacts, limits, and the path ahead. *Proceedings of the National Academy of Sciences*, *109*(31), 12302–12308. https://doi.org/10.1073/pnas.0912953109

Polit, D. F., & Beck, C. T. (2010). Generalization in quantitative and qualitative research: Myths and strategies. *International Journal of Nursing Studies*, *47*(11), 1451–1458. https://doi.org/10.1016/j.ijnurstu.2010.06.004

Poveda J, Abril-Urias P and Escobar C (2020) Biological Control of Plant-Parasitic Nematodes by Filamentous Fungi Inducers of Resistance: *Trichoderma*, Mycorrhizal and Endophytic Fungi. *Front. Microbiol*. 11:992. doi: 10.3389/fmicb.2020.00992

Provin, T. L., & Pitt, J. L. (2019, March 4). *Phosphorus - What does high phosphorus in soil mean?* Texas A&M AgriLife Extension Service. Retrieved September 19, 2020, from https://agrilifeextension.tamu.edu/library/gardening/phosphorus-too-much-and-plants-may-suffer/#:%7E:text=The%20buildup%20of%20phosphorus%20in,those%20nutrients%20in%20the%20soil.

Ramírez-Valdespino CA, Casas-Flores S and Olmedo-Monfil V (2019) Trichoderma as a Model to Study Effector-Like Molecules. *Front. Microbiol.* 10:1030. doi: 10.3389/fmicb.2019.01030

Reid, G., Wong, P., & Alt, S. (2013). *Soil Bacteria and Fungi - NSW | Fact Sheets | soilquality.org.au*. SoilQuality. Retrieved on September 16, 2020, from http://www.soilquality.org.au/factsheets/soil-bacteria-and-fungi-nsw

Rengel, Z., Tang, C., Raphael, C., & Bowden, J. W. (2000). Understanding subsoil acidification: effect of nitrogen transformation and nitrate leaching. *Soil Research*, *38*(4), 837. https://doi.org/10.1071/sr99109

Ribaudo, M. (2006, July 1). *USDA ERS - Hypoxia in the Gulf: Addressing Agriculture's Contribution*. USDA ERS. Retrieved on September 15, 2020, from https://www.ers.usda.gov/amber-waves/2006/july/hypoxia-in-the-gulf-addressing-agricultures-contribution/

Riquelme, M., Aguirre, J., Bartnicki-García, S., Braus, G. H., Feldbrügge, M., Fleig, U., Hansberg, W., Herrera-Estrella, A., Kämper, J., Kück, U., Mouriño-Pérez, R. R., Takeshita, N., & Fischer, R. (2018). Fungal Morphogenesis, from the Polarized Growth of Hyphae to Complex Reproduction and Infection Structures. *Microbiology and Molecular Biology Reviews*, *82*(2), 1–47. https://doi.org/10.1128/mmbr.00068-17

Rivera-Méndez, W., Obregón, M., Morán-Diez, M. E., Hermosa, R., & Monte, E. (2020). Trichoderma asperellum biocontrol activity and induction of systemic defenses against Sclerotium cepivorum in onion plants under tropical climate conditions. *Biological Control*, *141*, 104145. https://doi.org/10.1016/j.biocontrol.2019.104145

Rudisill, M. A., Bordelon, B. P., Turco, R. F., & Hoagland, L. A. (2015). Sustaining Soil Quality in Intensively Managed High Tunnel Vegetable Production Systems: A Role for Green Manures and Chicken Litter. *HortScience*, *50*(3), 461–468. https://doi.org/10.21273/hortsci.50.3.461

Ryu, C.-M., Farag, M. A., Hu, C.-H., Reddy, M. S., Wei, H.-X., Pare, P. W., & Kloepper, J. W. (2003). Bacterial volatiles promote growth in Arabidopsis. *Proceedings of the National Academy of Sciences*, *100*(8), 4927–4932. https://doi.org/10.1073/pnas.0730845100

Sahebani, N., & Hadavi, N. (2008). Biological control of the root-knot nematode Meloidogyne javanica by Trichoderma harzianum. *Soil Biology and Biochemistry*, *40*(8), 2016–2020. https://doi.org/10.1016/j.soilbio.2008.03.011

Sannino, F., & Gianfreda, L. (2001). Pesticide influence on soil enzymatic activities. *Chemosphere*, *45*(4–5), 417–425. https://doi.org/10.1016/s0045-6535(01)00045-5

Satterthwaite, D., McGranahan, G., & Tacoli, C. (2010). Urbanization and its implications for food and farming. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 2809–2820. https://doi.org/10.1098/rstb.2010.0136

Sawyer, J. (2000, August 7). *Phosphorus Basics | Integrated Crop Management*. Phosphorous Basics. Retrieved on September 19, 2020, from https://crops.extension.iastate.edu/encyclopedia/phosphorus-basics

Schlatter, D., Kinkel, L., Thomashow, L., Weller, D., & Paulitz, T. (2017). Disease Suppressive Soils: New Insights from the Soil Microbiome. *Phytopathology®*, *107*(11), 1284–1297. https://doi.org/10.1094/phyto-03-17-0111-rvw

Schnürer, J., & Rosswall, T. (1982). Fluorescein Diacetate Hydrolysis as a Measure of Total Microbial Activity in Soil and Litter. *Applied and Environmental Microbiology*, *43*(6), 1256–1261. https://doi.org/10.1128/aem.43.6.1256-1261.1982

Scow, K.M. (1997). Soil microbial communities and carbon flow in agroecosystems. p. 367–413. In L.E. Jackson (ed.) *Ecology in agriculture*. Academic Press, San Diego, CA

Segoli, M., & Rosenheim, J. A. (2012). Should increasing the field size of monocultural crops be expected to exacerbate pest damage? *Agriculture, Ecosystems & Environment*, *150*, 38–44. https://doi.org/10.1016/j.agee.2012.01.010

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance

Climate Change Adaptation. (2012) A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

Sharpley, A. N., Smith, S. J., & Naney, J. W. (1987). Environmental impact of agricultural nitrogen and phosphorus use. *Journal of Agricultural and Food Chemistry*, *35*(5), 812–817. https://doi.org/10.1021/jf00077a043

Shoresh, M., Harman, G. E., & Mastouri, F. (2010). Induced Systemic Resistance and Plant Responses to Fungal Biocontrol Agents. *Annual Review of Phytopathology*, *48*(1), 21–43. https://doi.org/10.1146/annurev-phyto-073009-114450

Siegner, A., Sowerwine, J., & Acey, C. (2018). Does Urban Agriculture Improve Food Security? Examining the Nexus of Food Access and Distribution of Urban Produced Foods in the United States: A Systematic Review. *Sustainability*, *10*(9), 2988. https://doi.org/10.3390/su10092988

Smith, S. E., & Smith, F. A. (2011). Roles of Arbuscular Mycorrhizas in Plant Nutrition and Growth: New Paradigms from Cellular to Ecosystem Scales. *Annual Review of Plant Biology*, *62*(1), 227–250. https://doi.org/10.1146/annurev-arplant-042110-103846

Sofo, A., Milella, L., & Tataranni, G. (2010). Effects ofTrichoderma harzianumstrain T-22 on the growth of two *Prunus* rootstocks during the rooting phase. *The Journal of Horticultural Science and Biotechnology*, *85*(6), 497–502. https://doi.org/10.1080/14620316.2010.11512704

Sofo, A., Tataranni, G., Xiloyannis, C., Dichio, B., & Scopa, A. (2012). Direct effects of Trichoderma harzianum strain T-22 on micropropagated shoots of GiSeLa6® (Prunus cerasus×Prunus canescens) rootstock. *Environmental and Experimental Botany*, *76*, 33–38. https://doi.org/10.1016/j.envexpbot.2011.10.006

Steiner, G., Geissler, B., & Schernhammer, E. (2019). Hunger and Obesity as Symptoms of Non-Sustainable Food Systems and Malnutrition. *Applied Sciences*, *9*(6), 1062. https://doi.org/10.3390/app9061062

Swinburn, B. A., Kraak, V. I., Allender, S., Atkins, V. J., Baker, P. I., Bogard, J. R., Brinsden, H., Calvillo, A., De Schutter, O., Devarajan, R., Ezzati, M., Friel, S., Goenka, S., Hammond, R. A., Hastings, G., Hawkes, C., Herrero, M., Hovmand, P. S., Howden, M., … Dietz, W. H. (2019). The Global Syndemic of Obesity, Undernutrition, and Climate Change: The Lancet Commission report. The Lancet, 393(10173), 791–846. https://doi.org/10.1016/s0140-6736(18)32822-8

Swisher, R., & Carroll, G. C. (1980). Fluorescein diacetate hydrolysis as an estimator of microbial biomass on coniferous needle surfaces. *Microbial Ecology*, *6*(3), 217–226. https://doi.org/10.1007/bf02010387

Thirkell, T. J., Charters, M. D., Elliott, A. J., Sait, S. M., & Field, K. J. (2017). Are mycorrhizal fungi our sustainable saviours? Considerations for achieving food security. *Journal of Ecology*, *105*(4), 921–929. https://doi.org/10.1111/1365-2745.12788

Trauttman, N., Porter, K., & Wagenet, R. (n.d.). *PSEP :: Fact sheets :: Modern Agriculture: Its Effects on the Environment*. Cornell University Cooperative Extension. Retrieved September 16, 2020, from http://psep.cce.cornell.edu/facts-slides-self/facts/mod-ag-grw85.aspx

Travis, M. (2017, July 1). Leaf Mold Compost. UW Pepin County Extension. Wisconsin, Pepin County. Retrieved on September 16, 2020, from https://pepin.extension.wisc.edu/files/2017/08/170801-Leaf-Mold.pdf

Tucci, M., Ruocco, M., de Masi, L., de Palma, M., & Lorito, M. (2010). The beneficial effect of Trichoderma spp. on tomato is modulated by the plant genotype. *Molecular Plant Pathology*, *12*(4), 341–354. https://doi.org/10.1111/j.1364-3703.2010.00674.x

United Nations. (2018, May 16). *68% of the world population projected to live in urban areas by 2050, says UN*. UN DESA | United Nations Department of Economic and Social Affairs. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

United Nations. (2019, June 18). *Growing at a slower pace, world population is expected to reach 9.7 billion in 2050 and could peak at nearly 11 billion around 2100*. UN DESA | United Nations Department of Economic and Social Affairs. https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html

United States Geological Survey. (n.d.). *Pesticides in Groundwater*. Retrieved September 16, 2020, from https://www.usgs.gov/special-topic/water-science-school/science/pesticides-groundwater?qt-science_center_objects=0#qt-science_center_objects

University of Illinois Extension (n.d.) Chlorosis. Retrieved on September 17, 2020, from https://web.extension.illinois.edu/focus/index.cfm?problem=chlorosis

University of Massachusetts Extension. (2020, April 14). *Guidelines to Nitrogen Application on Agronomic Crops in Massachusetts*. Center for Agriculture, Food and the Environment. https://ag.umass.edu/crops-dairy-livestock-equine/fact-sheets/guidelines-to-nitrogen-application-on-agronomic-crops-in#:%7E:text=For%20established%20grass%20apply%20up,yield%20for%20the%20next%20cutting.

University of Minnesota Extension (n.d.) Understanding nitrogen in soils. Retrieved on September 17, 2020, from https://extension.umn.edu/nitrogen/understanding-nitrogen-soils#organic-n-sources-760712

USDA NRCS (1996 August). Soil Quality Indicators: Aggregate Stability. Retrieved on September 20, 2020, from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052820.pdf

USDA NRCS (2011) Carbon to Nitrogen Ratios in Cropping Systems. Retrieved on September 16, 2020, from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd331820.pdf

USDA NRCS (n.d. a) Healthy Soils are: high in organic matter. Retrieved on September 16, 2020, https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/health/?cid=stelprdb1193043

USDA NRCS (n.d. b) Soil Organic Matter: Soil Quality Kit – Guides for Educators. Retrieved on September 15, 2020 from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053264.pdf

USDA NRCS (n.d. c) Unlock the Secrets in the Soil. Retrieved on September 16, 2020, from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1101660.pdf

USDA. (2020, March 26). *USDA Makes it Easier to Feed Kids and Those Who Need Food During the COVID-19 National Emergency*. Retrieved September 16, 2020, from https://www.usda.gov/media/press-releases/2020/03/26/usda-makes-it-easier-feed-kids-and-those-who-need-food-during-covid#:%7E:text=WASHINGTON%2C%20March%2026%2C%202020%20%E2%80%93,local%20staff%20who%20serve%20them.

van der Heijden, M. G. A., Martin, F. M., Selosse, M.-A., & Sanders, I. R. (2015). Mycorrhizal ecology and evolution: the past, the present, and the future. *New Phytologist*, *205*(4), 1406–1423. https://doi.org/10.1111/nph.13288

Van Meter, K. J., Van Cappellen, P., & Basu, N. B. (2018). Legacy nitrogen may prevent achievement of water quality goals in the Gulf of Mexico. *Science*, *360*(6387), 427–430. https://doi.org/10.1126/science.aar4462

Vinale, F., Sivasithamparam, K., Ghisalberti, E. L., Marra, R., Woo, S. L., & Lorito, M. (2008). Trichoderma–plant–pathogen interactions. *Soil Biology and Biochemistry*, *40*(1), 1–10. https://doi.org/10.1016/j.soilbio.2007.07.002

Wade, J., Culman, S. W., Logan, J. A. R., Poffenbarger, H., Demyan, M. S., Grove, J. H., Mallarino, A. P., McGrath, J. M., Ruark, M., & West, J. R. (2020). Improved soil biological health increases corn grain yield in N fertilized systems across the Corn Belt. *Scientific Reports*, *10*(1), Open. https://doi.org/10.1038/s41598-020-60987-3

Wallenstein, M. (2017 Jan. 29) Are microbes the next revolution coming to Big Ag? *MarketWatch*. Retrieved from https://www.marketwatch.com/story/are-microbes-the-next-revolution-coming-to-big-ag-2017-01-27

Wang X-X, Zhao F, Zhang G, Zhang Y and Yang L (2017) Vermicompost Improves Tomato Yield and Quality and the Biochemical Properties of Soils with Different Tomato Planting History in a Greenhouse Study. *Front. Plant Sci.* 8:1978. doi: 10.3389/fpls.2017.01978

Weil, R. R., Islam, K. R., Stine, M. A., Gruver, J. B., & Samson-Liebig, S. E. (2003). Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. *American Journal of Alternative Agriculture*, *18*(1), 3–17. https://doi.org/10.1079/ajaa2003003

Weller, D. M., Raaijmakers, J. M., Gardener, B. B. M., & Thomashow, L. S. (2002). Microbial Populations Responsible for Specific Soil Suppressiveness to Plant Pathogens. *Annual Review of Phytopathology*, *40*(1), 309–348. https://doi.org/10.1146/annurev.phyto.40.030402.110010

Wertheim-Heck, S., Raneri, J. E., & Oosterveer, P. (2019). Food safety and nutrition for low-income urbanites: exploring a social justice dilemma in consumption policy. *Environment and Urbanization*, *31*(2), 397–420. https://doi.org/10.1177/0956247819858019

Weston, L. A., & Mathesius, U. (2013). Flavonoids: Their Structure, Biosynthesis and Role in the Rhizosphere, Including Allelopathy. *Journal of Chemical Ecology*, *39*(2), 283–297. https://doi.org/10.1007/s10886-013-0248-5

Wielemaker, R., Oenema, O., Zeeman, G., & Weijma, J. (2019). Fertile cities: Nutrient management practices in urban agriculture. *Science of The Total Environment*, *668*, 1277–1288. https://doi.org/10.1016/j.scitotenv.2019.02.424

World Bank. (2020). *Food Security and COVID-19*. Retrieved on September 16, 2020, from https://www.worldbank.org/en/topic/agriculture/brief/food-security-and-covid-19

Yedidia, I., Benhamou, N., & Chet, I. (1999). Induction of Defense Responses in Cucumber Plants (Cucumis sativus L.) by the Biocontrol AgentTrichoderma harzianum. *Applied and Environmental Microbiology*, *65*(3), 1061–1070. https://doi.org/10.1128/aem.65.3.1061-1070.1999

Zasada, I. (2011). Multifunctional peri-urban agriculture—A review of societal demands and the provision of goods and services by farming. *Land Use Policy*, *28*(4), 639–648. https://doi.org/10.1016/j.landusepol.2011.01.008

Zeffa, D. M., Perini, L. J., Silva, M. B., de Sousa, N. V., Scapim, C. A., Oliveira, A. L. M. . d. e., Amaral Júnior, A. T. . d. o., & Azeredo Gonçalves, L. S. (2019). Azospirillum brasilense promotes increases in growth and nitrogen use efficiency of maize genotypes. *PLOS ONE*, *14*(4), e0215332. https://doi.org/10.1371/journal.pone.0215332

Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D. B., Huang, Y., Huang, M., Yao, Y., Bassu, S., Ciais, P., Durand, J.-L., Elliott, J., Ewert, F., Janssens, I. A., Li, T., Lin, E., Liu, Q., Martre, P., Müller, C., Asseng, S. (2017). Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences*, *114*(35), 9326–9331. https://doi.org/10.1073/pnas.1701762114

Ziska, L. H., Pettis, J. S., Edwards, J., Hancock, J. E., Tomecek, M. B., Clark, A., Dukes, J. S., Loladze, I., & Polley, H. W. (2016). Rising atmospheric CO 2 is reducing the protein concentration of a floral pollen source essential for North American bees. *Proceedings of the Royal Society B: Biological Sciences*, *283*(1828), 20160414. https://doi.org/10.1098/rspb.2016.0414

CHAPTER 4. CONCLUSION

Urban food insecurity in the form of food deserts affects many college campuses, including Purdue University, and our survey results indicate that many graduate students experience both individuals and structural barriers when accessing nutrient-dense fruits and vegetables. Students without personal vehicles appear especially vulnerable to the negative effects from the local food landscape. Many more graduate students discussed how the food shock caused by the COVID-19 pandemic added even more barriers to access. Increasing local production of fresh produce from urban farms and community gardens appears to be one method of forging a stronger, more durable food system from which individuals living in areas of low access can receive supplementary help. Urban operations are often quite small and need to maximize the land they are allotted. The results of these experiments build upon both current research and ancient wisdom that recycling organic material from composted leaves into the soils of agricultural production sites simultaneously improves the productivity and health status of a soil, while creating an environment more conducive to fungal community growth and abundance. The reduction of transplant shock deaths due to *T. harzianum* inoculations builds upon mounting evidence that microbial inoculants can be utilized as effective agricultural treatments in the field when introduced in soils that supports their survival. These results provide optimism that agriculture, particularly urban agriculture, can continue to innovate and feed the rapidly increasing global population.

APPENDIX A. COMPLETE SURVEY

Purdue Graduate Students' Fresh Produce Consumption in the Food Desert

---

Start of Block: Demographic Information

1) Sex

- ○ Male
- ○ Female
- ○ I prefer not to answer

---

2) Are you currently pursuing a Master's degree or a PhD at Purdue University?

- ○ Master's
- ○ PhD

---

3) Are you a United States citizen or International student? (If international, please list your country(s) of citizenship)

- ○ United States citizen
- ○ International student ____

---

4) Which program will you be receiving your degree from? (Please check all that apply)

- ☐ Agriculture
- ☐ Engineering
- ☐ Health/Human Services
- ☐ Liberal Arts
- ☐ Krannert Management
- ☐ Pharmacy
- ☐ Education
- ☐ Science
- ☐ Other ____

---

5) Which option best describes your work/school responsibilities this semester? (Please check all that apply)

- ☐ Research/Lab work
- ☐ Classes
- ☐ Teaching

---

6) Which option best describes your transportation status?

- ○ I drive my own personal vehicle while at Purdue
- ○ I rely on public transportation to get to places
- ○ I rely on friends and family to drive me around to places
- ○ I rely on ride-sharing companies like Uber to get to places
- ○ I mainly get around by walking, bike, skateboard, or scooter

---

7) Which option best describes who pays your cell phone bill? (Check all that apply)

- ☐ Myself
- ☐ Parents
- ☐ Other Family Member
- ☐ Spouse
- ☐ Friend
- ☐ I do not own a cell phone

---

8) Which best describes the location of your primary living space?

- ○ On campus
- ○ Off campus within a 5 minute drive of campus
- ○ Off campus with a 5+ minute drive to campus

---

9) In one sentence, why did you complete this survey?

____

End of Block: Demographic Information

Start of Block: Fruit and Vegetable Consumption

Fruit Serving Sizes

-Apple, pear, orange, peach or nectarine: 1 medium

-Avocado: Half of a medium

-Banana: 1 small

-Grapefruit: Half of a medium

-Grape: Around 16

-Kiwi: 1 medium

-Mango: Half of a medium

-Melon: Half-inch thick wedge (All melons)

-Pineapple: 1/4 of a medium

-Strawberry: 4 large

(Courtesy of the American Heart Association)

10) In the past 24 hours, approximately how many servings of **fruit** (Fresh, Canned or Frozen) have you consumed in each of the different time frames?

	0	1	2	3	4	5+
Breakfast	○	○	○	○	○	○
Mid-Morning Snack	○	○	○	○	○	○
Lunch	○	○	○	○	○	○
Mid-Afternoon Snack	○	○	○	○	○	○
Dinner	○	○	○	○	○	○
Late-Night Snack	○	○	○	○	○	○

Vegetable Serving Sizes

-Bell Pepper: Half of a large

-Broccoli/Cauliflower: 5-8 florets

-Carrot: 6 baby or 1 whole medium

-Corn: 1 small ear or half of a large ear

-Leafy vegetable: 1 cup raw or 1/2 cup cooked

-Potato: Half of a medium

-Squash, yellow: Half of a small

-Sweet Potato: Half of a large

-Zucchini: Half of a large

(Courtesy of the American Heart Association)

11) In the past 24 hours, approximately how many servings of **vegetables** (Fresh, Canned or Frozen) have you consumed in each of the different time frames?

	0	1	2	3	4	5+
Breakfast	○	○	○	○	○	○
Mid-Morning Snack	○	○	○	○	○	○
Lunch	○	○	○	○	○	○
Mid-Afternoon Snack	○	○	○	○	○	○
Dinner	○	○	○	○	○	○
Late-Night Snack	○	○	○	○	○	○

End of Block: Fruit and Vegetable Consumption

Start of Block: Fresh Produce Consumption

12) Where does the majority of fresh produce you consume come from?

- ◯ Supermarket
- ◯ Restaurants
- ◯ Cafeterias
- ◯ Convenience Store
- ◯ Personal Garden, Local Farmer
- ◯ Food Pantries

---

13) Where do you go for the majority of the fresh produce you cook and eat at home?

- ◯ Walmart
- ◯ Aldi
- ◯ Payless
- ◯ Farmer's Market
- ◯ Fresh Thyme
- ◯ Purdue ACE Food Pantry
- ◯ Online
- ◯ Other ____

---

14) In the last year, where have you gotten fresh produce?

- ☐ Walmart
- ☐ Aldi
- ☐ Payless
- ☐ Farmer's Market
- ☐ Fresh Thyme
- ☐ Purdue ACE Food Pantry
- ☐ Online
- ☐ Other ____

15) How important are each of these factors when purchasing fresh produce?

	Not at all important	Slightly unimportant	Neither important nor unimportant	Slightly important	Very important
Taste	○	○	○	○	○
Freshness	○	○	○	○	○
Low Price	○	○	○	○	○
High Price Ensuring High Quality	○	○	○	○	○
Nutrition	○	○	○	○	○
Convenience/Easily Prepared	○	○	○	○	○
Food Safety	○	○	○	○	○

16) I include fresh produce in my diet because:

____

17) Is fresh produce difficult to include in your diet? (If yes, please explain why. If no, please write "No.")

____

End of Block: Fresh Produce Consumption

Start of Block: Coronavirus Considerations

18) How has the recent coronavirus epidemic affected food purchasing and preparation habits?

____

19) How has the coronavirus pandemic affected the importance of the following factors when obtaining groceries?

	I feel that this is LESS important than it was before the coronavirus pandemic	I feel that this is JUST AS IMPORTANT as it was before the coronavirus	I feel that this is MORE important than it was before the coronavirus pandemic	I did not feel this was important before the coronavirus pandemic and I still do not feel that it is important
Taste	o	o	o	o
Freshness	o	o	o	o
Price	o	o	o	o
Nutrition	o	o	o	o
Convenience/Easily Prepared	o	o	o	o
Food Safety	o	o	o	o

20) Once the situation returns to normal, how likely are you to have your groceries delivered to your place of residence?

- ◯ More than I did before the coronavirus pandemic
- ◯ The same as I did before the coronavirus pandemic
- ◯ Less than I did before the coronvirus epidemic
- ◯ I did not shop for groceries in this way before the coronavirus pandemic and I won't after the pandemic

---

21) Once the situation returns to normal, how likely are you to order your groceries online and physically pick them up at the supermarket?

- ◯ More likely than I did before the coronavirus epidemic
- ◯ Just as likely as I did before the coronavirus epidemic
- ◯ Less likely than I did before the coronavirus epidemic
- ◯ I did not shop for groceries in this way before the coronavirus pandemic and I won't after the pandemic

---

22) How would you describe the level of difficulty associated with food purchasing during the coronavirus pandemic?

- ○ Harder than normal
- ○ The same as normal
- ○ Easier than normal

---

23) How would you describe your current overall fruit and vegetable consumption compared to pre-coronavirus pandemic times?

- ○ I am eating more fruits and vegetables than during normal times
- ○ I am eating the same amount as I did during normal times
- ○ I am eating less fruits and vegetables than during normal times

---

24) How do you believe the coronavirus pandemic has affected volunteering needs?

- ○ There is a greater need for people to volunteer somewhere than during normal times
- ○ There is a similar need for people to volunteer somewhere than during normal times
- ○ There is a less need for people to volunteer somewhere than during normal times

---

25) How much risk are you putting yourself in when volunteering during the coronavirus pandemic? (Please indicate the level of risk for the following volunteering opportunities.)

	No Risk At All	Very Little Risk	Average Risk	Slightly Above Average Risk	Extreme Level of Risk
Hospital Volunteering	○	○	○	○	○
Blood Drive Volunteering	○	○	○	○	○
Assisted Living/Retirement Home/Older Adult Volunteering	○	○	○	○	○
Food Distribution Volunteering	○	○	○	○	○
Community Garden Volunteering	○	○	○	○	○

End of Block: Coronavirus Considerations

Start of Block: Community Garden Participation

Community Garden- A single piece of land gardened collectively by a group of people. Community gardens utilize either individual or shared plots on private or public land while producing fruit, vegetables, and/or plants grown for their attractive appearance. (Wikipedia)

26) Are there any community gardens within a 15 minute drive of your place of residence?

- ○ Yes
- ○ No
- ○ Unsure

27) How often do you volunteer at a community garden?

- ○ Weekly
- ○ Monthly
- ○ Once every 6 months
- ○ Once a year
- ○ I do no volunteer at any community gardens

28) What value does a community garden bring to the communities where they are located?

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Community gardens help those in need put food on the table	○	○	○	○	○
Community gardens increase the community's sense of togetherness	○	○	○	○	○
Community gardens care about improving the environment in which they are embedded in	○	○	○	○	○
Community gardens are a necessary element in a functioning community	○	○	○	○	○

29) What value have you personally experienced from a community garden? (If none, please write "None".)

____

30) What experience, positive or negative, have you had with a community garden? (If no experience, please write "None".)

____

31) I would be more likely to volunteer at a local community garden if: (Please indicate the degree to which you agree or disagree with the following statements)

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Opportunities to volunteer were better communicated to me	○	○	○	○	○
Transportation to and from was provided for me	○	○	○	○	○
I knew the community garden staff were friendly and accomodating	○	○	○	○	○
I knew my level of gardening experience was accepted	○	○	○	○	○
I had the proper clothing	○	○	○	○	○
Opportunities did not conflict with my schedule	○	○	○	○	○
I was able to take home fresh produce from the garden	○	○	○	○	○

32) Are you interested in volunteering at a community garden?

- ◯ Yes
- ◯ No

---

33) What is the best method for a community garden to convey information about the work they do and volunteering opportunities?

- ◯ Text
- ◯ Email
- ◯ Social Media Pages
- ◯ Other ____

End of Block: Community Garden Participation

APPENDIX B. SURVEY CODEBOOK

Completed codebook is on a Microsoft Excel document and can be accessed by emailing kyle.richardville12@gmail.com.