12-2022

Food Security & Urban Agriculture - Considerations for Soil Improvements and Crop Planning

Aaron Sedivy
University of Nebraska-Lincoln, aaron.sedivy@huskers.unl.edu

FOOD SECURITY & URBAN AGRICULTURE -

CONSIDERATIONS FOR SOIL IMPROVEMENTS AND CROP PLANNING

by

Aaron Michael Sedivy

A DOCTORAL DOCUMENT

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Plant Health

Major: Plant Health

Under the Supervision of Professor Gary L. Hein

Lincoln, Nebraska

December, 2022

FOOD SECURITY & URBAN AGRICULTURE -

CONSIDERATIONS FOR SOIL IMPROVEMENTS AND CROP PLANNING

Aaron Michael Sedivy, DPH

University of Nebraska, 2022

Advisor: Gary L. Hein

Urban agriculture provides many benefits, such as energy conservation, rainwater remediation, increased aesthetic and property value, and therapeutic use for physical, cognitive, and emotional wellbeing. Urban agriculture can also provide critical integrity to each pillar of food security: availability, access, utilization, and stability. As urban agricultural activities increase, social interactions will follow in concert. This will provide opportunities for building trust through the two-way communication of contrasting perspectives, cultures, and beliefs using impartial narratives. Growers can use knowledge and understanding gained from these positive social interactions to formulate their personal paradigms for practice and better meet the needs of each stakeholder. Growers of all levels of expertise are encouraged to constantly investigate assumptions and build capacity for understanding their socio-environmental systems. Special considerations are suggested in this document for developing desirable characteristics in urban soils and for designing a food crop production plan that is in continuous evolution with the production system.

TABLE of CONTENTS

CHAPTER ONE -- 1

DYNAMIC SYSTEMS - A NEED FOR URBAN AGRICULTURE --------------------- 1

Food Security --- 1

Adapting to Climate Change with Urban Agriculture --------------------------------- 4

Social Interactions -- 8

Personalized Paradigm for Practice -- 9

Conclusion ---10

CHAPTER TWO---12

PURSUIT OF THE PERFECT SOIL --12

Soil Testing ---14

Soil Pollution and Contamination ---15

Soft Soil --20

Aeration ---20

Black Soil --22

Carbon Cycle & Sequestration --23

Soil Organic Matter (SOM) --24

Water Infiltration --26

Fine Texture --27

Cation Exchange Capacity ---27

Nutrient Cycling --29

Deep and Even ---31

Conclusion ---34

CHAPTER THREE ---35
URBAN CROP PRODUCTION PLANNING --35
Evaluate the System --36
Develop a Production Plan---39
Production Schedule--39
Pest Management Plan--41
Review and Revise --45
Implement the Production Plan ---45
Conclusion ---47
REFERENCES --49

CHAPTER ONE

DYNAMIC SYSTEMS - A NEED FOR URBAN AGRICULTURE

The positive impacts exposure to plants has on physical, cognitive, and emotional health have been well documented in scientific literature (APHA, 2013; Donovan et al., 2013; Koncikowski & Capozziello, 2021; Pedlowski et al., 2002; Relf, 2021). Spending time in nature is now being prescribed by some physicians (Thompson, 2018) through "green care" as a substitute for, or in combination with, pharmaceutical drugs. Additionally, increased aesthetic and property value, energy conservation, rainwater remediation, and more are widely supported benefits of plants growing in an urban setting (Echevarría Icaza & Van der Hoeven, 2017; Kondo et al., 2017; Narango et al., 2017; Nowak et al., 2006, 2013). However, this chapter will focus on urban agriculture as a tactic to help address local food insecurity and respond to climate change. Also, important considerations in addressing this complex socio-ecological system will be identified.

Food Security

As defined during the 1996 World Food Summit, "Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2008). The Food and Agriculture Organization of the United Nations (FAO) has identified four pillars required for food security: availability, access, utilization, and stability.

Availability is the physical presence of nutritious food in the food system, often on a larger scale (i.e. global, regional, and community). One way to think of availability is that if it is on the grocery store shelf, a local market, or in the home garden, it is available; however, availability does not equal consumption.

Access typically addresses food security on a smaller, household scale. There are three factors that can limit a household's access to nutritious food: financial ability, distance to the store or market, and socio-cultural restrictions. Communities in rural U.S. are often at a higher risk of food insecurity due to more limited access than their urban counterparts. This is a result of the significant physical distance from the home to the market and limited access to social programs for alleviating food security. If the market is the individual's home garden, access could be restricted by the ability to harvest the crop (for example: out-of-reach fruit in a tree or root crops buried below frozen soil). Socio-cultural restrictions occur when a household has the financial means and transportation to get the food, but they are denied by force (based on their social group, sex, gender, etc.) or pressured to choose not to access the required nutrition (i.e. religious dietary restrictions, norms on acceptable foods) (Olum et al., 2017).

Utilization is a household's familiarity with the food that is available and their knowledge of how to process it appropriately. This definition of food security includes both nutritional and caloric needs; therefore, an obese individual can be, and likely is, food insecure due to a lack of adequate nutrition in their diet (Ashley, 2016). Highly processed foods are often less nutritious than the food crops in their unprocessed form (Shewfelt, 2017). The increased availability and access to familiar foods in their unprocessed form can improve the nutritional quality of an urban farming household's diet.

Stability is when all of the previous three pillars are accounted for, at all times. There can be breaks in a household's or region's food stability that are chronic, transitory, or seasonal. Chronic food insecurity can be either long term (continuous for an extended period of time) or persistent (continues in spite of significant remediation efforts). Transitory food insecurity is short-term and temporary. Somewhere between chronic and transitory falls seasonal food insecurity, usually predictable and cyclical. Many cultures have historically staved off seasonal availability by canning and preserving food for winter months; whereas today, particularly in developed nations, food is readily shipped in from regions that can produce food year-round. These predictable issues with food security can be more manageable than unexpected supply problems following severe weather and natural disasters associated with climate change.

The timing of severe weather events in relation to crop growth stage has been shown to have the greatest impact on yield reductions. In Europe, Powell and Reinhard (2016) showed that at week 27 of wheat production (around the beginning of July), a single high temperature event can cause an expected 5% loss in yield. Evaluating a 70-year period in the Midwestern U.S., the total yield of maize was reduced by 8.1% to 17.5% from drought stress in the study area (Wang et al., 2016). These are significant losses resulting from extreme weather; however, maize and winter wheat are less vulnerable than forage grass, potatoes, and onion (van Oort et al., 2023). This high correlation between yield loss and weather extremes is supported by a shift in crops produced. A study in the Netherlands found that impacts of climate change have driven one third of the participating producers to reduce production of onions and potatoes and increase production of wheat (van Tilburg & Hudson, 2022). As yield losses from severe weather continue in field-produced vegetable crops and fewer acres are planted, the market prices can be expected to increase. This will directly impact food security and may drive more people to begin urban gardens, particularly in low-income countries (Poulsen et al., 2015).

Adapting to Climate Change with Urban Agriculture

Climate change is a highly debated topic, with its root cause at the forefront of criticism. However, no matter the reason, weather events around the world are becoming less predictable and more severe as a result of increasing levels of atmospheric carbon dioxide. *Whether* humans are the underlying cause of this change or not, humans can slow the progression of climate change by reducing the rate at which carbon is released into the atmosphere.

A logical way to reduce carbon emissions from food production is to grow the right foods close to where people live and outsource food when local production does not meet local demands. In 1950, 30% of the global (including the United States) population was living in urban settings, growing to 55% in 2018, and it is expected to reach nearly 70% in 2050 (United Nations et al., 2018). For comparison, the percent of the total population living in urban settings in 1980 was 39.4% of the world (not including the U.S.) population and 73.7% of the United States population; in 2000, 46.7% (world) and 79.1% (U.S.); and in 2020, 56.2% (world) and 82.7% (U.S.) (United Nations &

Population Division, 2020). Expansion of urban agriculture is a necessary component in addressing the complex question of how to feed a growing population.

By growing food close to where it is consumed, the potential for disruptions in the food distribution chain can be reduced. This helps maintain both pillars of Availability and Sustainability. By increasing the numbers of people directly participating in food production, the Access and Utility pillars can be made more stable. When COVID-19 shut down production, services, and transportation in general throughout the world, people were left cooking for themselves, often from scratch (Bennett et al., 2021). A study by Sarda *et al.* (2022) surveyed 2,422 people and found that 22.0% reported having a more balanced diet during lockdown, 19.5% reported a less balanced diet, and 58.5% reported no perceived change. Of those participants that reported a more balanced diet, 54.8% provided the reason as having more time to prepare meals. In contrast, rationale for perceiving a less balanced diet included skipping meals (reported by 12.0%), having difficulty finding certain foods (35.9%), and preparing their own meals (15.9%). As the nutritional value of a food is often influenced by how it is processed (Shewfelt, 2017), it can be reasoned that if an event were to occur, which has similar impacts on food supply chains but no increase in a households' available meal-prep time, the household's food security will be compromised. As more people become involved with food production through an increase in urban agriculture, they will have a say in what is grown. Therefore, they may be more familiar with the food and how to process and prepare it.

The need for urban agriculture is well supported; however, there is still the question of it being enough to feed the population. As long as there is adequate growing space, high enough yield productivity, and enough labor available, an urban household can grow enough vegetables to meet their five servings per day needs (Glavan et al., 2018). These three requirements are intricately linked. The growing environment is directly correlated to yield productivity. The higher the productivity, the less space required, but likely more labor is needed. The less suitable the environment is to the crop(s), the lower the production capacity could be. In addition to yield (as in total edible biomass produced), the nutrition of those products is also negatively affected by adverse growing conditions (Brouder & Volenec, 2017; FAO, 2008; Khan et al., 2015; Taub et al., 2008). Concentrations of labile potassium, phosphorus, magnesium, and calcium are greatly influenced by soil temperature and moisture. As temperatures increase, soil adsorption is decreased for anions and increased for cations. Increased CO_2 concentrations reduce transpiration rates and therefore mass flow of nutrients into plant roots. This may lead to lower nutritional value of crops as CO_2 concentrations increase (Pilbeam, 2015). When grown under the elevated CO_2 concentration projected for the year 2100, the reduction in protein concentration in potatoes, barley, rice and wheat is 13.9%, 15.3%, 9.9% and 9.8%, respectively (Taub et al., 2008). To achieve the same desired production goals in nutritional value, more labor (including production inputs such as fertilizers, irrigation, etc.) and space will be required. If time or labor is the limiting factor, productivity will likely be lower than its maximum potential; therefore, more space will be needed.

In a geospatial study of Boston, USA, Saha & Eckelman (2017) showed that if all 10% of the available land within the city is converted to food production and all 42% of the available rooftop area is used for hydroponics, the upper limit of fruit and vegetable production would be enough to meet nutritional requirements for 1.5 times the population of the city. It is unreasonable to expect that the total available land and rooftops would be converted to food production but converting a portion of these spaces could make a significant impact. Costello et al. (2021) showed that implementing urban agriculture as part of an area's food production system will improve the crop diversity, but the radius of required land to fulfill total nutritional needs of the population may not be significantly reduced (Costello et al., 2021). This low impact on land requirement is attributed to the lack of adequate vitamin D, vitamin B_{12}, or calcium in fruits and vegetables to meet all nutrient requirements of the population. These findings support the use of supplements and development of fortified produce to aid in reducing the environmental impact of food production.

In an urban setting, traditional garden space is often the least available of these three requirements, with much of urban soils paved over and/or heavily polluted. To overcome this limitation in production space, people have found creative alternative spaces through the use of balconies, rooftops, indoor space, community gardens, vacant lots, guerilla gardening and more. Urban environments are often hostile to plants, with many designed to prevent plant growth by paving exposed soil and redirecting rainwater to quickly flow away. With unfavorable growing conditions limiting yield potential and a shortage of available growing space, urban agricultural production systems will require increased labor, inputs, and knowledge to maximize production.

Social Interactions

Increasing agricultural activities in limited spaces, such as in community gardens, will increase the opportunity for social interaction (Carolan & Hale, 2016). With exposure to beauty in nature, pro-social behaviors increase and people become more trusting and generous (J. W. Zhang et al., 2014). Although, as more individuals enter the conversation, opposing positions on best production practices and environmental stewardship are destined to clash. Building trust will be critical to encourage and maintain participation in urban agriculture over the long-term (Reed, 2008).

In order to keep people involved, the social environment must feel safe from ridicule and judgement (Bledsoe & Baskin, 2014; M. K. Brown et al., 2009). Trust between parties on opposing sides of a disagreement makes reaching a mutually accepted solution more likely (Young et al., 2016). Framing statements in specific ways can engage certain audiences (Wolsko et al., 2016) and disengage others. In order to have two-way communication, it is critical that the narrative remains impartial (Whitmarsh & Corner, 2017). How individuals respond and how long they stay engaged or involved can determine the success or failure of an urban agriculture discussion or program (Reed, 2008). Each of these aspects are difficult to establish and maintain but are significantly more so when crossing cultures (Briggs et al., 2019).

Without understanding the cultures of each stakeholder, significant mistakes in designing a production plan can be made through misinterpretations and unfamiliarity of cultural norms, behaviors and ideologies (Deng et al., 2022). These community interactions can be used throughout a growing season to modify production practices to better meet the needs of the stakeholders (Glynn et al. 2018), much like the use of formative assessments in Education (Black & Wiliam, 2009).

Through open communication, we begin to understand the various factors that influence production choices of our neighboring farmers. This provides us with opportunities to learn from each other, solve problems in urban agriculture, and constantly improve our production systems.

Personalized Paradigm for Practice

Complex problems require complex solutions, and those involving biological systems are always complex. Never is there only one right answer. To build adequate complex solutions, all elements of the issue must be addressed. When evaluating the elements of an issue, it is important to be wary of our tendencies towards reductionism, which "aims to reduce diverse observations to general relationships that predict new observations with precision and accuracy" (Brunner, 2006). The human brain is constantly bombarded with information. It simplifies this information for its own protection, to conserve cognitive capacity, and to solve complex problems (Myers & DeWall, 2018; E. R. Smith & DeCoster, 2000).

To understand issues of food production and food security, we have reduced highly complex natural systems into simplified constructs. This abbreviated version has given humankind a foundational understanding of living systems and how they interact with their environments, in order to manipulate the system to our benefit. With the increased understanding of simplified systems, our brains can then consider more information, little by little. This is the basis of scientific research. It is imperative that the pieces discovered through scientific studies are communicated and connected to create more robust paradigms and influence further research.

Paradigms are generally accepted views, ideas, theories or sometimes beliefs on a given subject (G. Brown & Desforges, 1977; Kuhn, 1970). We use paradigms to interpret the world around us. Over time, new discoveries through scientific research may change our understanding, causing a paradigm shift. Ideally, a paradigm shift in agriculture leads to a consensus on the *best* way to produce food. The more we learn about science, nature, and food production, the more apparent it is that what is best under certain conditions, may not be so under others. A single paradigm through which all food is produced is impractical and inconsiderate of the individuals growing the food. It is important that food producers of all kinds pull ideas and practices from multiple agricultural paradigms to design solutions that are best suited to their specific situation.

Conclusion

Increasing diversity within all aspects of the food system will be critical in reducing production-associated inputs and negative environmental impacts, while ensuring a greater balance in the four pillars of food security - availability, access, utilization, and stability. Increasing diversity specifically in agricultural production increases complexity and labor. Whereas large-scale field agriculture is designed to reduce variability, small-scale urban farming can help fill this ecological role. When an area is impacted by severe weather or pests, a portion of the intended crops are more likely to be salvageable if there is greater diversity in the crop species, species genetics, sizes of farms, and management strategies practiced (van Tilburg & Hudson, 2022). To better ensure food security, more people are needed to produce food for themselves and their communities. Urban agriculture alone will not end world hunger or solve the climate crisis, nor will any single change. However, it can contribute to the solution, while improving a household’s and a community’s food resilience.

CHAPTER TWO

PURSUIT OF THE PERFECT SOIL

Gardeners of varying expertise understand the importance of soil, and many will spend small fortunes in pursuit of their ideal garden soil. For many gardeners, this is a soft, black, and fine soil, which has been tilled deep and even. Such soil is glorious to work and can yield picture-perfect root vegetables. This perceived ideal is perhaps describing Mollisol soils. Throughout history, Mollisols have been recognized world-wide as highly productive soils for agriculture and hold many of these desired characteristics (X. Liu et al., 2012). However, Mollisols are not essential for most vegetable crops, and obtaining this ideal soil is not always economically practical nor environmentally responsible. Home gardeners do not have the same regulatory oversight as large-scale agricultural production systems where many inputs are highly regulated and have a direct impact on the financial viability of the operation. Urban agricultural inputs and resource consumption are often greater than in conventional agricultural production systems (Goldstein et al., 2016; Mok et al., 2014). While urban agriculture is an important component in addressing food security, it also must maintain a positive impact on the environment and climate change. Establishing and maintaining the ideal qualities in garden soil, whether native or relocated soil, often requires significant yearly inputs of resources (i.e. synthetic fertilizers, tillage), and this can be highly destructive to the microbial community in the soil. These activities can lead to an increased release of carbon dioxide, further exacerbating climate change, and can indicate inefficient uses of resources (Chabbi et al., 2017; Goldstein et al., 2016; Mok et al., 2014).

Soil is not an unlimited resource. Urban expansion is consuming adjacent land which had historically been used for agricultural production and biodiversity preservation (Hatfield et al., 2017; P. Smith et al., 2010). However, the desirable properties of urban soils are different from those of agricultural soils. As land is developed for urban use, soil properties are changed to better suit the new requirements by increasing soil strength, and reducing water retention and infiltration. (Kempfert & Gebreselassie, 2006; Streich et al., 2013). Those who have attempted to grow plants in recent construction sites can attest.

As agriculturally productive soils are covered and compromised, maintaining the productivity of the remaining soil is increasingly important. This shortage of space and quality soils has in part inspired innovations in urban agriculture that use soil-alternative production methods, such as controlled environment agriculture, vertical farming, rooftop farming, hydroponics, aeroponics and others (Armanda et al., 2019). Alternatives such as these may be the best option for many production systems and their stakeholders; however, start-up and production costs are significantly higher in these soil-alternative systems. To provide application to the broadest audience, this chapter will focus on urban soils for horticultural food crop production. This chapter will justify the need for testing urban soils and address the characteristics of an ideal garden soil **– soft, black, and fine, which has been tilled deep and even –** by examining the desirable function(s) each of these characteristics provide for plant growth, identifying common practices used to achieve this soil standard, and providing alternatives that consider long-term ecological impacts.

Soil Testing

For those that decide to grow plants in soil for food production, ornamental use, or dual purpose, testing the soil for contaminants, pH, soluble salts, plant nutrients, soil organic matter, mineral content, and soil texture is an important first step. Often, the visible characteristics and qualities of an urban soil, such as compaction, color, water infiltration, plant growth responses, etc., can lead to replacing or amending the available soil before it is tested. However, topsoil is not standardized, and the buyer is not guaranteed the qualities of ideal gardening soil. Topsoil may be more expensive than the purchasing cost per cubic yard and delivery fees. Topsoil can be a source of pests and diseases and also contain contaminants of heavy metals and other toxic substances (Boente et al., 2017). Plants can pull many of these contaminants from the soil, and if consumed by animals, the toxins can accumulate and cause disease if critical concentrations are reached (Nagajyoti et al., 2010).

Covering or exchanging soil can be a successful strategy to mitigate known soil contaminants. However, pollution-free soils available for purchase in an urban area are often collected from deep in the soil profile and lack adequate organic matter, plant-available nutrients, and optimal soil characteristics to grow healthy crops (Egendorf et al., 2018; Walsh et al., 2018). Ideally, soil purchased for mitigation of known contaminants would be tested for soil qualities before it is applied to the area. Soil that does not meet the needs of the grower can be rejected or modified to fulfill requirements prior to installation. Rather than purchasing soil in its complete, ideal stage, growers can develop these characteristics in their soil over time. However, a soil analysis is necessary to maximize crop production potential with minimal inputs.

Soil Pollution and Contamination

Knowledge of the contaminants found in urban soil, garden amendments, mulch, water and other inputs can be used to develop strategies and practices that minimize their bioavailability, uptake potential, and toxicity risk to humans and the environment (Rodríguez-Eugenio et al., 2018). Heavy metals are highlighted because they are the most persistent pollutant found in urban soils and pose a high risk to human health. In the U.S., 23% of urban soils with homes built before 1980 are estimated to be contaminated with hazardous concentrations of lead (Kessler, 2013). A study in Belgium showed urban gardeners are at high risk for exposure to urban soil contaminants through gardening activities and consumption of contaminated food. Evaluations of fruit and vegetables showed that 30% of vegetables produced in urban gardens were above normal market concentrations, 83% of root vegetables were non-compliant in lead, and 77% of greens were non-compliant for cadmium levels. Similarly, blood and urine samples showed moderately higher concentrations of lead than in the non-gardening population, arsenic at double the levels of the non-gardening population, and cadmium levels higher than 95-97.5% of the non-gardening population (Petit et al., 2022).

Heavy metals are named so because of their high densities, although their chemical properties are what make them toxic even at low levels. Heavy metals of greatest concern include lead, mercury, cadmium, zinc, arsenic, nickel, copper, selenium, molybdenum, and chromium (Khan et al., 2015; Nagajyoti et al., 2010; US EPA, 2007).

Sewage fertilizers, phosphate fertilizers, contaminated water, organic and synthetic pesticides, and other common food crop production inputs can be sources of heavy metals (Nagajyoti et al., 2010). All soils can be a source of heavy metal pollution caused by human activity. Due to various chemical and physical properties of clay, clay soils can also be a natural source of contamination through erosion of the soil's parent rock (Alloway, 2013; Sparks, 2003b). Examples include cadmium, lead, nickel, and zinc in soils originating from Jurassic limestone, and arsenic, cadmium chromium, copper, mercury, molybdenum, nickel, lead, and zinc from black shales (Alloway, 2013). Therefore, even if site history does not indicate a significant risk of anthropogenic pollution, there could be naturally occurring contamination from heavy metals.

Lead is the heavy metal most commonly tested for and it can be used as an indicator of potential contamination of other heavy metals (Kessler, 2013). Many soil tests only evaluate concentration, but concentration alone does not provide enough information to assess risk. In addition to concentration, testing the bioavailability - a compound's ability to interact chemically, physically, or biologically with living organisms - of heavy metals in the soil, water, and garden inputs is necessary for developing adequate management strategies. Key factors to consider when evaluating heavy metal exposure risk in soil include the soil texture (especially clay content), pH, soil organic matter, bulk density (aeration), water table levels, flooding potential, temperature, and human/soil contact potential. Exposure risk can also be impacted by the crop and its sensitivity to the pollutant of concern, uptake pathways and storage, and intended use (Kessler, 2013; Rodríguez-Eugenio et al., 2018; Sparks, 2003c; US EPA, 2007).

Some heavy metals, such as nickel, copper, zinc and molybdenum, are essential for plant growth, development, and cellular functions, but they are required in only small amounts (Pallardy, 2008). Their uptake by plants is not only dependent on their concentration in the soil or their chemical form but also the characteristics of the soil. Soil type, pH, organic matter, cation exchange capacity, and moisture content are additional factors that influence uptake of heavy metals by plants (Khan et al., 2015; Rodríguez-Eugenio et al., 2018).

Bioaccumulation occurs when these, or any toxic substances, build up within an organism faster than they can be broken down or eliminated from the organism. A well-known example of bioaccumulation is elevated mercury levels in predatory fish, such as tuna (Ordiano-Flores et al., 2011). Individually, the fish ingested contain relatively low levels of mercury but levels accumulate to hazardous amounts in the tuna's tissues as it consumes additional fish with low levels of mercury. Bioaccumulation of heavy metals in plants can change the oxidation state of the metal (Ma et al., 2001; Sparks, 2003a). This change can make the heavy metal more toxic (Rahman & Naidu, 2009) or lower the plants' nutritional value (Khan et al., 2015). Increasing the consumption of vegetables and other whole, plant-based foods is an essential public health goal of many dieticians, nutritionists, and medical professionals (FAO & WHO, 2017). However, households can follow sound dietary guidelines by meeting the recommended servings of fresh produce, yet still be undernourished due to heavy metal contamination in the garden soil.

Many commonly grown vegetable crops have been shown to contain concerning levels of heavy metals (Khan et al., 2015; Q. Yang et al., 2011; Zhou et al., 2016).

However, the concentrations measured in the edible plant parts does not necessarily equal the bioavailable dose (Paltseva et al., 2020). The most significant risk of ingesting certain soil pollutants, such as lead, may not be through consuming plant material grown in polluted soils, but rather by directly ingesting polluted soil and dust (Paltseva et al., 2020; US EPA, 2001). Concentrations of aluminum, chromium, iron and titanium in plant tissues can be used to indicate the source of heavy metal pollution as either plant uptake, or soil particle inclusion (Cary et al., 1994; Egendorf et al., 2018; McBride et al., 2014). The concentrations of these metals in plant tissues are low (or regulated as is the case with iron); therefore, their presence in tissue analyses would indicate the presence of soil particles in the tissue sample. To reduce the exposure risk of soil particle pollution, the US EPA recommends maintaining soil coverage to reduce erosion, thoroughly washing produce before ingesting, and discarding skins of root vegetables and outermost leaves of greens (US EPA, 2011). An adequate layer of mulch can help reduce the amount of dust that becomes airborne, is transferred to living quarters, or can splash onto the above-ground, consumable plant parts. Ideally, urban soils with known or expected contamination would be mitigated to reduce the risk of exposure to contaminated dust, even if the space is not used for gardening activities or food production.

Remediation efforts can be directed at the soil, through replacing, sealing, or covering contaminated soils, or directed at the contaminant, by reducing bioavailability with amendments, or phytoremediation. In some cases, it may be necessary to have contaminated soils removed and replaced with “clean” soil or install physical soil barriers under raised garden beds before filling with uncontaminated soil (Paltseva et al., 2020; Walsh et al., 2018). Keep in mind that the purchase of topsoil is not a guarantee that it is contaminant-free, as prior testing is not always required or adequate (Egendorf et al., 2018). Reducing the bioavailability of some soil contaminants can be achieved by integrating amendments, such as organic matter, calcium (i.e. lime), phosphate and iron oxide, to adjust the soil pH and/or sorb the contaminant(s) (Paltseva et al., 2020; Sparks, 2003c; US EPA, 2007).

The ability of some plants to stabilize, take up, and store soil contaminants can be exploited for the benefit of the environment. This strategy, called phytoremediation, uses living plants to filter, stabilize, extract, transform, and/or volatilize contaminants from the soil (Ma et al., 2001; Oladoye et al., 2022; Shen et al., 2022). These processes have evolved to preserve the plants' health and provide benefits in this context. Unfortunately, plants cannot metabolize inorganic heavy metals to transform them into non-toxic or less toxic forms. In this case, the plant material may need to be harvested and decontaminated or appropriately "disposed of" to prevent the contaminants from re-entering the system (Oladoye et al., 2022; L. Yang et al., 2022). Based on the Law of Return, repeated harvesting of a crop over time can deplete contaminants from the soil. In the case of phytoremediation, the crop is not intended to be consumed, but instead grown and harvested to remove the contaminants from the environment. Harvested plant materials can be reduced in volume through compaction, microbial, and heat treatments. The heavy metals can then be recovered through various extraction procedures (Z. Liu & Tran, 2021).

Soft Soil

Mollisols are a taxonomic Order of soils that are generally considered the most agriculturally productive soils and have many of the ideal garden soil characteristics (Soil Survey Staff, 1999). The Latin root of Mollisol, *mollis*, translates to "soft." A soft soil can indicate adequate aeration for plant growth. Plant roots and soil microbes need to respire to grow, and soil aeration allows for gas exchange deep into the soil profile. Whether harvested for the roots or not, all garden plants need roots for structural support, nutrient absorption, water uptake and to store energy.

Plants use sunlight, water, and carbon dioxide to make sugars (carbohydrates) and release oxygen. Sugars are produced in green tissues and translocated to tissues that are consuming energy and storing the sugars. Cells of all living organisms grow through respiration (Alderson & Rowland, 1989) where the chemical bonds in the sugar are broken to produce the energy required for cell expansion and elongation. Root cells require oxygen to break the bonds in the glucose sugars to create energy where it is needed for cellular growth and activity (Hillel et al., 2005; Pallardy, 2008). Although roots are usually not exposed to light, they do a significant amount of growth. They do not have oxygen available as a byproduct of photosynthesis like cells in the green tissues do, so they must pull it in from the atmosphere around the roots.

Aeration

Poor aeration in soils can result from compaction, flooding, or an impermeable layer at the soil surface, such as concrete. In these soils, gases from above ground cannot filter through the networks of channels in the soil (i.e., soil pores) to reach the roots

(Inglett et al., 2005). Concrete hardscapes surrounding planting spaces may not physically restrict root exploration into the soil underneath but will reduce the soil's capacity for gas exchange. Clay soils are the most susceptible to poor aeration due to their small particle size and shape (Sparks, 2003). To improve drainage and soil compaction, amending the soil is a common technique. Soil amendments are anything that is added to the soil to improve soil characteristics. Usually, the deeper these amendments are integrated the more beneficial they are, often through mechanical tillage. Particularly in soils with heavy clay and low porosity, it is recommended to amend the soil by mixing in highly fibrous, carbon-based materials (Davis & Whiting, 2013). Examples of carbon-based amendments include leaves, wood chips, saw dust, paper, manure and compost. As a clay soil dries, its strength increases and becomes more difficult to penetrate (Jin et al., 2013; Kempfert & Gebreselassie, 2006). However, when wet, it is highly susceptible to further compaction (Eden et al., 2020), particularly in the soil below the amended portion. Mechanical tillage can provide immediate benefits, but these are often short-lived as tillage destroys soil structure and disturbs microbial communities (Drijber et al., 2000; Jacobs et al., 2022; Zheng et al., 2022).

Roots vary in soil-penetration abilities, by both species and genotype (Jin et al., 2013). Root penetration of strong soils is improved by reducing root-soil friction (root exudates and sloughing of root cap and border cells), reducing pressure on the root tip (through increasing root diameter), increasing root growth pressure (by relaxing cell walls), altering hormone concentrations (increased ethylene synthesis, reduced abscisic acid metabolism and cytokinin and auxin concentrations), and maintaining a more vertical direction of root growth (Jin et al., 2013). Plants with higher soil penetration abilities can be used to remediate soil compaction. Bio-tillage is a technique that uses plant roots to change the soil structure to better accommodate the requirements of desired plant crops (Z. Zhang & Peng, 2021). These plants can create tunnels through compacted soils when their roots penetrate the dense soil layers. After the plants die, these root voids, called biopores, are left in place, and the fibrous organic matter from the roots is integrated into the soil without excessively disturbing the soil structure. Biopores are relatively large channels that provide spaces for gases, water, and roots of more sensitive plants (Jin et al., 2013) to infiltrate the soil profile more effectively. The increase in drainage further improves water infiltration and soil aeration (Eden et al., 2020). By growing plants tolerant to the current conditions, the structure and properties of the soil can be altered to accommodate more desirable plants which may be sensitive to low soil oxygen levels, have larger root diameters, and/or lower root expansion force. Bio-tillage requires planning, and it can take multiple growing seasons to achieve the desired improvement in soil conditions. A greater diversity of root architectures through species diversity, has greater positive impacts on soil properties (i.e., soil carbon, aggregate diversity, and plant-available nutrients) (Saleem et al., 2020).

Black Soil

Mollisols also are dark in color due to their high organic matter content and are alternatively called “black soils” (X. Liu et al., 2012). All organic matter is made of carbon, thus all organic matter is sequestered carbon. The carbon reserves maintained in soil organic matter have been identified as having a significant role in sequestering atmospheric carbon dioxide; therefore, these carbon reserves contribute to moderating climate change (Chabbi et al., 2017; Kruse et al., 2013). High organic matter in soils has been linked to an increase in nutrient availability and water infiltration. Organic matter can prevent heavy metal pollutants and other anthropogenic chemicals from leaching into the waterways, being ingested by animals, or taken up by food crops, by binding to the pollutants (Khan et al., 2015; Tang et al., 2014). High soil organic matter increases water infiltration rate, but has also been overestimated in its role in water holding capacity and plant available water reserves of soil. Whereas the increase in water holding capacity from organic matter is insignificant compared to the influence from soil textures. Increasing organic matter will have the greatest impact on increasing water holding capacity in sandy soils low in organic matter (Minasny & McBratney, 2018).

Carbon Cycle & Sequestration

Carbon sequestration is a process in which atmospheric carbon (CO_2) is converted to long-term storage structures and compounds (Agostini et al., 2015). Most plants take up atmospheric carbon in the form of carbon dioxide and make sugars through photosynthesis. These sugars are then used to build cells during growth to form leaves, roots, flowers, seeds, wood, etc. Plants can also release sugars through their roots to feed soil microorganisms (Bonfante & Genre, 2010). These plant-associated soil microbes can provide the plant with increased access to water and nutrients. Every living organism needs a source of carbon to grow; thus, all living things have sequestered carbon. When a plant or any part of one dies its carbon is eventually consumed by herbivores, decomposers, or fire. Through respiration, organisms release gaseous carbon back into the atmosphere as carbon dioxide, and through cellular shedding, defecation, and death, carbon is released into the environment for other animals and fungi to consume (Trivedi et al., 2018).

In essence, each year, the carbon sequestered by annual plants is released into the surrounding environment to be decomposed, where 60-80% is then released back into the atmosphere (Hoorman & Islam, 2010). Perennial plants sequester carbon for longer-terms with the extent of carbon mass and time sequestered dependent on how much material is kept alive or protected from one season to the next. Perennials discard a portion of above- and below-ground tissues with every dormant cycle, no matter if they are temperate or tropical, allowing decomposers to break down those shed tissues.

Woody plants slow decomposition of their carbon more than other types of plants. Wood is made of dense, complex compounds of carbon chains that require specialized cellulolytic and ligninolytic enzymes to break them down. Old, dead wood is protected in the center of the stem and trunk, physically shielding it from organisms that would otherwise consume it. However, trees and shrubs still regularly shed leaves, branches, bark, roots and reproductive structures (Pallardy, 2008).

Soil Organic Matter (SOM)

The process of how carbon in the soil is consumed and made stable or resistant to degradation is under debate. There are several competing theories, with two leading paradigms being the traditional Humification Model and the more recent Soil Continuum Model (Lehmann & Kleber, 2015). In humification, large carbon compounds from plant and animal residues are continuously broken down by organisms into smaller compounds. These smallest carbon compounds become glued together by microbes and form humus. Humus is large, complex, particles of organic matter that are difficult for decomposing organisms to consume. In the Soil Continuum Model, the initial steps are similar; however, carbon particle sizes continuously get smaller and smaller as they are consumed and broken down by lower trophic-level organisms. These smaller organic particles increase in stability by binding to soil particles. Sticky, extracellular polymeric substances and remains of soil microorganisms adhere soil particles together forming “aggregates” (Costa et al., 2018). As carbon sources are encapsulated within aggregates, they are protected from decomposition. The smallest, encapsulating microaggregates protect soil-sequestered carbon over the long-term better than the larger macroaggregates (Six et al., 2004), because the larger aggregates are more likely to be broken up.

However organic matter is made stable and inaccessible, soil carbon stabilization takes time. Throughout the process of soil carbon stabilization, of the organic debris to enter the soil complex 3-8% is stored as microbial biomass, 3-8% as microbial products and active soil organic matter, and 10-30% as humified organic matter. In total, 20-40% of the organic matter to enter the soil complex is sequestered in the soil. 60-80% of carbon that enters the soil complex is released back into the atmosphere as CO_2 (Hoorman & Islam, 2010). With time, microbial activity will continue to consume carbon from the non-humified stores (6-16%) as they become accessible. On average, soil microbes will store an average of 40% of the total carbon they consume, as living tissues (Widdig et al., 2020).

Any dead plant tissues underground are potential sources of food for most soil microbes. When organic matter (carbon) is added to soil to make it better for growing plants, it is not the plants that use the carbon, but decomposers such as saprophytic fungi and decomposing bacteria. In fact, plants have been shown to release carbon (exudates) from their roots in order to stimulate surrounding saprophytes and decomposing bacteria to break down carbon sources in the soil (Birgander et al., 2017; Cheng et al., 2012; Drigo et al., 2010; van Groenigen et al., 2017). During this process of carbon mineralization in soils, other nutrients are made available for the plants and plant-associated fungi, such as arbuscular mycorrhizae (AMF) and ectomycorrhiza (EMF). Mycorrhizae are typically more efficient than plants in accessing nutrients. When levels of plant-accessible nutrients are low, and plants have associated AMF, plants will transfer more carbon to the AMF in exchange for nutrients required for photosynthesis and other biological processes of the plant (Birgander et al., 2017; Cheng et al., 2012; Drigo et al., 2010).

Water Infiltration

Water infiltration and drainage rates can be increased with increasing soil organic matter. The presence of carbon sources in the soil can indicate a high level of microbial activity. As microbes consume carbon, grow, multiply, and die, they help to develop and stabilize soil aggregates. Aggregate sizes form a continuum from persistent microaggregates (ranging from 2-20μm) to microaggregates (ranging between 20-250μm), to macroaggregates (greater than 250μm) (Brady & Weil, 2002; Costa et al., 2018; Six et al., 2004). As aggregate sizes increase, the size of pore spaces surrounding the aggregates increase as well. The network of pores in the soil can be filled by gas or water. As pores increase in size and quantity, both water and air can move faster and more easily through the soil profile resulting in higher permeability and infiltration rates (Streich et al., 2013). High water infiltration rates can reduce flooding, standing water on the soil surface, and water lost through evaporation (Soil Survey Staff, 1999; Sparks, 2003a; US EPA, 2007)**.** As water moves through the soil profile, it helps to incorporate plant nutrients, organic matter, and soil amendments into the rhizosphere.

Fine Texture

Soil texture is determined by its composition of sand, silt, and clay. Mollisols are high in clay and silt and are considered fine textured soils that include silty clay loam or silt loam soils (Soil Survey Staff, 1999; Streich et al., 2013). The balance of sand, silt and clay in loam soils is often considered to be ideal for optimizing the production of traditional agronomic and horticultural crops. Texture is debatably the most difficult soil characteristic to change. As mentioned previously, many urban growers choose to bring in “new" topsoil to improve the soil texture in their gardens. However, soil is not a renewable resource, purchased soil is not guaranteed to be a fine textured classification, and can itself be a source of pollution, pests, and diseases (Boente et al., 2017). Fortunately, high cation exchange capacity and high mineral content (qualities that make fine textured soils famously productive) can be developed in local soils that are less conducive to high crop production.

Cation Exchange Capacity

Cation exchange capacity (CEC) in soil is its ability to hold onto positively charged particles called cations. Some examples of cations are calcium, magnesium, and potassium, which are plant macronutrients and required by plants (Pallardy, 2008). Soil that has a high CEC is better able to prevent these nutrients from leaching into the groundwater and surface water systems. High cation exchange capacity can mean less supplementation of nutrients is required to sustain high plant productivity compared to low CEC soils. Cation exchange capacity is greatly determined by soil type, with clay particles having the highest CEC and sand having the lowest. In soils with low clay content, CEC can be improved by increasing the stable soil organic matter in the soil (Trivedi et al., 2018).

A soil's cation exchange capacity is heavily influenced by changes in pH. A low pH (acidic soil) satisfies the charge on the surfaces of the soil particles, making their bonds and attraction to cations weaker and conversely, stronger to the negatively charged anions. Examples of anions that are required in part for plant growth and development include: phosphate, sulfate, nitrate and chlorine (Pallardy, 2008). A neutral soil pH allows for higher nutrient availability to typical garden crops. Plants or their associated soil microbes can change the soil pH within rhizosphere microclimates slightly. In neutral soils, this change is often enough to weaken bonds of either cations or anions to soil particles and make them available for uptake, as needed (Sparks, 2003a). In soil with low cation exchange capacity, the CEC and pH can be improved through the addition of soil organic matter (Gruba & Mulder, 2015). This can increase plant available nutrients and reduce fertilizer requirements and the risk of excess nutrients escaping into the natural environment.

Nutrient Cycling

A high cation exchange capacity combined with a high mineral content can indicate high plant nutrient availability. However, soil with these characteristics does not ensure there will be adequate available nutrients when the plants require it. Nutrient demands vary between plant species, growth stages, nutrient types, nutrient forms, and a seemingly infinite set of conditions. However, nutrient demands are typically highest during stages of active plant growth, particularly when biomass is increasing at the highest rate (Heckman et al., 2009). In cases where nutrient availabilities are higher than the intended crop demands, excess nutrients can cause nutrient toxicity (Pallardy, 2008; White & Brown, 2010). These excess nutrients can also be "lost" from the soil system through leaching, erosion, volatilization (Sparks, 2003c), and utilization by other plants and organisms, causing various environmental concerns (Dobermann et al., 2022).

Nutrient deficiencies in a plant can make it more difficult for the plant to recover from the effects of the deficiencies. Without adequate nutrition, growth is inhibited. Reductions in plant growth can cause a plant to be less competitive for resources that limit plant growth and health. Specifically, reductions in root growth can prevent a plant from gaining access to new nutrient deposits. In relation to plant-associated microbes, deficient plants may not have "disposable" resources to divert to their associated microbial community. In addition to growth, proper nutrition is important for effective plant defense systems (Huber et al., 2012), making them more tolerant of stresses from both biotic and abiotic factors.

One goal in urban agriculture is to produce food. This requires the removal of some part of the plant (i.e., seeds, fruit, leaves, stems, and/or roots). Even if growers follow the Law of Return, nutrients will be in the red after every harvest. This natural law was first described in scientific literature by Sir Albert Howard (1943), where the "return of waste material to the soil…balanced the losses of humus involved in production." In the context of Sir Howard's publication, the term "waste" is meant to include all organic matter from a dynamic farming system that includes animal husbandry, not just the unused portions of the crop grown in specific soil. This "law" requires the return of all non-harvested material back to the soil they were taken from, reducing the removed nutrients potentially by a significant amount. Effects on plant health and overall performance may be slight and slow, thus difficult to notice in the short-term, but soil fertility and crop productivity potential is reduced with every harvest. For long-term production, the growing system requires the replacement of at least as much as is removed by way of carbon, nutrients, and minerals. This replacement must also account for the needs of other essential organisms in the system.

When required nutrients are limiting crop production, the use of synthetic fertilizers is a relatively easy way to fulfill the nutritional needs of the crop, with a quick plant response. Synthetic fertilizers are an important tool for managing plant growth and health; however, it is more beneficial to the natural system to fulfill plant nutrition needs with organic waste. The preference for synthetic fertilizers is not unlike the use of supplements in human nutrition where daily multivitamins should be unnecessary if a balanced diet is available and consumed. What was meant to "supplement" deficiencies in a diet has become a standard in many cultures (Anjorin et al., 2019; Garcia-Casal et al., 2019; Jayatissa & Fernando, 2019; Mishra & Potischman, 2021). Regardless of whether the agriculture system is conventional, certified organic, or regenerative, nutritional requirements of a harvested crop cannot be met without supplementation. Higher production pressure to harvest higher yields requires greater inputs.

Deep and Even

A common reason people start a garden, and continue through the seasons, is for the therapeutic benefits it can provide (Koncikowski & Capozziello, 2021). Uniformity within a system reduces complexity (Gu & Chou, 2022), and soils are no exception. Working in uniform systems allow for implicit memories to direct decision-making; therefore, less cognitive processing is required than in more variable systems (Beratan, 2007; E. R. Smith & DeCoster, 2000). We know what to expect.

Whether the soil is considered compacted or not, as soil depth increases, so does soil strength (the ability to resistance deformation) (Kempfert & Gebreselassie, 2006). Uniformly loose and even textured soils have high workability, as loose soils do not require as much force to penetrate as settled soils, reducing the physical effort required to work the soil. A highly workable soil is not just for the benefit of the laborer's back, but it can directly impact crop productivity. As roots reach deeper into the soil profile, the increasing soil strength makes it more difficult for root exploration and expansion (Jin et al., 2013). Deep and loose soils will restrict root growth less than contrasting soils. Less restriction on root growth results in increased crop productivity and quality (Shaheb et al., 2021).

Uniformly loose, fine, and even textured soils allow for more efficient crop management regarding placement of the plant material at its optimal depth and spacing. Called the tilth of a soil, these qualities in a seedbed allow for even distribution and germination, easier root penetration into the soil, and faster plant development (Chisi & Peterson, 2019; Firman & Allen, 2007; Gupta et al., 2012).

Tillage is an agricultural practice that disturbs the soil to improve conditions for crop production. When implemented well, as demonstrated by some conservation tillage practices, tillage can improve water infiltration, compaction, and organic matter content, and can be critical in pest management programs, without significantly compromising soil structure or lead to significant soil loss. To some extent, "tillage" is a natural process. Non-anthropogenic disturbances to the soil profile do occur naturally in large-scale disturbances (i.e. avalanches, glacial movement, windthrow, flooding), and more localized disturbances (i.e. through animal activities such as burrowing, burying, digging, and grazing).

A positive plant growth response can be seen after a tillage event. This can be explained by the destruction of aggregates which encase particulate organic matter and prevent it from being degraded further. When aggregates are broken up through events like tillage, the carbon and/or nutrients are no longer protected from microbes and can be consumed. As within all food webs, consumption produces waste. There are functional groups that have adapted to consume the "waste" from other groups, including carbon decomposers. With the increase in accessibility to organic matter, soil microbial activity from multiple functional groups can increase again. Some nutrients are made available for plants to uptake directly or through mycorrhizal associations, as previously mentioned. It is estimated that 84% of all plants have mycorrhizal associations with fungi, with some having multiple symbiotic relationships (van der Heijden et al., 2015).

Although, an increase in soil microbial activity, as observed after a tillage event, is not necessarily specific to those functional groups that assist plants. High microbial activity indicates the consumption and degradation of stored soil carbon (Six et al., 2004). This can potentially increase atmospheric carbon dioxide concentration and contribute to global warming. This activity can also result in microbes competing with plants for nutrients of limited availability. As with all good things, over- or improper use of tillage has consequences. In temperate climates, incorporating the organic debris into the soil in the fall can provide microbes enough time to flourish, rebalance, and reduce the demand for nutrients that are also essential for plant growth before crops are planted in the spring.

Soil strength is a factor in soil loss, erosion, and stability of infrastructure foundations. Whether the infrastructure is a tree or building, the surrounding soil provides support. By definition, urban gardens are in close proximity to buildings, and urban gardening must be considerate of this stabilizing function of urban soil. Gardening activities must not compromise the stability of adjacent buildings and their foundations. Tillage reduces soil strength. It can be logically reasoned that tilling too deep, too close to infrastructures will compromise their foundations and structural stability. Cementing agents, such as organic matter and sources of calcium (i.e., lime, bone meal, etc.), help to increase the strength of a soil by increasing soil aggregation (Egendorf et al., 2018; Kempfert & Gebreselassie, 2006). As an added benefit, the cementing agents also balance soil pH in acidic soils. Both results from increasing cementing agents also help to reduce the phytoavailability of heavy metals, such as lead (Paltseva et al., 2020).

On a small scale, such as in an urban garden, the greater effort required to work in a more complex soil may be negligible for the grower(s). Environmental and long-term production benefits of protecting soil aggregates may outweigh the lower physical strain required by the grower working in loose, fine, and even soil. These costs and benefits are difficult to measure and unique to every grower and their production system. Ideally, mechanical soil disturbances would be limited as much as possible.

Conclusion

Urban gardening has many benefits beyond its impact on the local food system. Unfortunately, it can also compromise a community's health through an increased exposure to urban soil pollution. Soil contaminants, such as heavy metals, can be directly ingested as soil particulate matter and dust, or indirectly by eating food grown in contaminated soils. Testing urban soils, particularly those used in food production, is necessary to prevent negative impacts from toxic contaminants. Soil tests can also guide growers through developing desirable characteristics of highly productive agricultural soils in their own urban gardens. Namely, through contaminant remediation, improved aeration, and preservation of sequestered soil carbon. Knowing the characteristics of a garden soil is the foundation for understanding its unique production system.

CHAPTER THREE

URBAN CROP PRODUCTION PLANNING

Vegetable gardens typically have high crop diversity. As crop diversity increases, so does the complexity of the production system. Even the most experienced grower and scientist would have difficulty designing a vegetable production program that includes an exhaustive account of each element in this framework. The production planning framework needs to anticipate as much as possible throughout the production season to minimize negative impacts and increase successes. The goal of this chapter is to offer urban gardeners a crop production framework that will assist them in making the *best* decisions for their unique system.

I encourage growers to use this planning framework to expand their understanding of their specific production system. The resulting plan for some may be basic at the beginning of production (i.e., limited to one crop). I challenge growers to further develop their production plans with each season, to always learn and grow. After all, "Decisions are only as good as the anticipatory system" - O'Brien et al., 2013. These recommendations for evaluating a production system are based on frameworks established in Integrated Pest Management (Bryant & Reay-Jones, 2020; Norris et al., 2003), business planning (EPA, 2011; Perez et al., 2015; Prial, 2019), and community economics (Emery & Flora, 2006).

Evaluate the System

The first step in formulating a plan is to describe the system. For an urban garden to have the greatest benefit, the needs of each stakeholder should be considered. In the context of this document, “stakeholder” is used to describe any individual with authority over or is impacted by the urban garden and its activities. In the case of a home garden, the stakeholders may be the members of the household, but could include neighbors and the greater community. Including each stakeholder in the early stages of planning will help to increase participation (Mattila et al., 2022). As individuals become more involved with their food choices and how it is produced, they are more likely to use and follow the plan, thus improving the Utility pillar of food security. Crops of cultural significance to the stakeholders are important for supporting Utility, as the consumer is likely familiar with how to prepare them. With the cost of food being a significant driver to begin an urban garden (Glavan et al., 2018), potential crops should account for their financial impact on the household. In this case, crops that are frequently purchased or have a high market cost may be candidates to consider. These needs can then be used to develop short and long term production goals.

Next, identify access to resources, such as financial, physical, social, and intellectual. Knowing the available financial support and alternate sources of funding will be factors in deciding on production and management options at later stages. Examples of physical resources include the available garden space, tools (i.e. hand tools, shovels, watering can, etc.), supplies (i.e. soil amendments, fertilizers, pest management products, twine, etc.), utilities (i.e. water and electricity), and labor (EPA, 2011). Social and intellectual resources can include local gardening clubs and associations, friends and family with gardening experience, and formal institutions (i.e., local university extension, research publications). These social and intellection resources should be thoroughly vetted to eliminate those with false or misleading information. Having plant production and management resources available can save time when finding an immediate answer is critical.

An urban garden is not a closed system. The local environment will influence what crops can be grown well and the inputs required to do so. As described in Chapter 2, the soil in an urban garden should be tested prior to planting. The results will influence crop productivity, management decisions, and use. Climactic factors, such as temperature ranges and averages, precipitation profiles, humidity, and solar radiation intensity, will be important when choosing crops that are most adapted to the production system. These are also necessary when designing a production schedule. Research the pests and beneficial organisms known to inhabit crops in the area. Local gardening associations and agricultural extension agencies will often provide relevant information on local pests, such as the species present, their pressure on specific crops, and timing of occurrence or movement through the area. Not only will this information influence choices in crop production, in some cases specific crops and their pests are regulated by the government, as seen with codling moth (Thistlewood & Judd, 2019) and whiteflies (Alvarez & Abud-Antún, 1995).

Total compliance with an area-wide pest management program can be essential to the food security of an entire country. In the 1980’s and 1990’s, whitefly, *Bemisia tabaci*

(A and B biotypes), spread quickly transmitting several *Geminiviridae* viruses across the Dominican Republic. Initially, growers relied heavily on chemical pesticides for control. However, resistance developed, biotype B was identified, and populations grew nearly unchecked to efficiently vector several viruses that cause plant diseases. The most impacted crops included beans, watermelon, cucumber, tomato, eggplant, pepper, potato, pumpkin, tobacco, cotton. In the production season of 1993 to 1994, regional tomato yields were reduced by as much as 90-95% by whitefly and its vectored viruses. In response, during a four-month period, the government issued nation-wide measures to ban specific crops, regulate planting times, destroy crops upon early infestation, remove crop residues, restrict transport of vegetative planting material, use whitefly traps for monitoring, and others. In 1994 to 1995, the production of four of these crops, including tomato, was coordinated across regions. A production rotation was implemented between regions for a maximum production period of three months in each area. In 1994-1995, the yield in tomatoes was improved drastically to a 20% loss (Alvarez & Abud-Antún, 1995)**.** Logically, urban gardens could be sources of pest populations. Theoretically, if local urban gardens did not comply with an area-wide pest management program, the program would likely be less successful.

Next is to evaluate the information gathered on the system. Use the collected data to choose crop species and cultivars that meet the needs of the stakeholders, are adapted to local growing conditions, and are available. Some crops initially desired by the stakeholders may not be suitable to the available system and can be removed from the list. Some may not be suitable for the environment or will surpass resource limits of the production system. Agricultural extension publications, food production organizations, gardening communities, and other reliable resources can be utilized for specific recommendations of proven crops and varieties for the area.

Tools like the Vegetable Variety Navigator, created by Loker and Wortman (2021) can also be used in selecting crop varieties. Through this interactive tool, growers can compare yield potential and quality and estimate adaptability of several horticultural crops and hundreds of varieties. In the initial release of the navigator tool, the study locations of included data can be filtered by crop type, variety, soil texture, and aridity to show the relative yield and years of data collected at each location. Individuals can filter this information according to their own growing conditions, to aid in the selection of crops and varieties to grow. The selected crop list can be used to identify necessary modifications to the production system, such as soil pollution remediation, soil quality improvements, or accessibility, if adequate resources are available.

Develop a Production Plan

Production Schedule

A production schedule will help the grower meet production goals. For each crop and pest, use climate data and growing degree days to establish a production timeline. Growing degree days predict development of a plant or insect, based on physiological responses to temperature. A growing degree day, or degree-day, is a unit to measure each 24-hour period an organism is exposed to a specific range of temperatures where development occurs. No development occurs when temperatures are below the minimum threshold or above the maximum threshold and development slows or stops when temperatures approach these thresholds (UC IPM, 2016). Degree-days can be used with recent or forecasted weather conditions to predict the developmental stage and rate of development in various crops, weeds, insects, and diseases for use in a crop production timeline and pest management plans. An example of these predictions includes the hours of continuous wetting required by many non-vectored plant pathogens to cause infection, where the number of hours the plant tissue is wet (leaves, buds, flowers, fruit, etc.) at certain temperatures can be used to predict disease. For example, powdery mildew (*Uncinula necator*) in grapes requires at least 12 hours of continuous wetness and temperatures between 50-60^{o}F for infection to occur (Gubler et al., 1999). To reduce pest pressure and improve crop performance, planting dates can be adjusted to avoid critical periods of high risk (Norris et al., 2003). When possible, account for relevant system and crop-specific factors that impact plant growth and development, such as soil temperatures, day length, nutrient availabilities and requirements, planting densities, water needs, and pollination requirements (Taiz et al., 2015).

Anticipate circumstances that will impact the production timeline, reduce the required reaction time, and may minimize negative impact on production and yield. For example, poor germination rates or an early crop failure can reduce the yield capacity by a significant amount. If appropriately planned, the crop can be replanted or inter-planted early enough to produce an alternate harvest.

Once crop development and pest occurrence are projected through the season, evaluate the schedule for compatibility between crops and pests and the ability to meet the needs of the stakeholders. Adjust any element as needed, and illustrate a map of the garden and planting plan. The plan can be multi-dimensional if implementing a succession planting and/or companion planting. Seeing a visual representation of the garden can help anticipate abiotic stresses that may cause deviations from the production schedule. Make adjustments to the map to prevent anticipated issues, or set a plan for how and when to address them. Microclimates within a garden can influence the accumulation of growing degree days. This can cause crops to mature at different rates than expected. If the rate is slower than projected in the production timeline, a crop may not yet be harvestable when needed. If the rate is too fast, crops can mature early, requiring an early harvest and potentially disrupt food availability. The microclimates within a garden can be used intentionally to manipulate crop production schedules and quality. Crops will often mature faster if grown in warmer microclimates, but will have a higher sugar content if grown under cooler conditions (Taiz et al., 2015; Zoecklein & Gump, 2022).

Pest Management Plan

To anticipate biotic stressors, design a pest management plan that can address each pest (plant, animal, and pathogen) identified in the ecology assessment, within reason. A detailed pest management plan can quickly become overwhelming. As experience and knowledge are gathered, gradually build on the pest management plan and develop capacity for understanding complex life systems. In the meantime, implement general pest management practices to reduce pest pressures and their impacts on yield. Examples of these general practices fall within two main categories, habitat modifications and host plant resistance. Habitat modifications for pest management are intended to discourage pests and encourage their natural enemies. Examples are to remove alternate host plant species, install temporary physical barriers (i.e., floating row covers), mulch with pest-free organic matter, and plant trap crops and native plants as year-round food and shelter for natural enemies. Effective host plant resistance begins with selecting resistant or tolerant crop species and varieties and sourcing plant materials that are pest-free. The crop will be better able to withstand pest pressure when plant health is maintained throughout the growing season. Provide each crop its optimum planting depth, spacing, density, and timing, and requirements for water, nutrition, light, and temperature to increase the crops ability to withstand pest pressure (Norris et al., 2003; Taiz et al., 2015).

Once pests are known or anticipated, it will be critical to understanding a pest's life cycle and habits for efficient and effective management of the pest. In the case of managing insect-vectored diseases, it is critical to understand the lifecycle of the disease, the vector(s), and how they interact with each other as well as the plant host. An insect vector's capacity to transmit plant pathogens is dependent on genetic factors of the insect, but also of the pathogen. In the case of whiteflies, gut bacteria populations may also influence their ability to transmit several plant viruses (Fiallo-Olivé et al., 2020). A further division of each pest by life stage will allow for increased specificity of management strategies, such as insect eggs vs. adults, and goose eggs vs. gosling (Maslo & Lewis, 2013). Life cycles and growing degree days can be used to predict development and reproduction of the crop(s), pest(s), and beneficial organisms. Incorporating data from life tables into a pest management plan can influence decisions that will lead to the greatest chances for successful pest management.

A life table for a pest shows how its population changes at each developmental stage, based on various natural causes of death. This information for an anticipated pest can be used to guide preventative as well as reactionary, or therapeutic, actions. For example, Naranjo and Ellsworth (2005) created a life table for silverleaf whitefly, *Bemisia tabaci*, showing that efforts to increase predation during the 4^{th} nymphal stage of the whitefly would be more efficient population management than increasing parasitism. In this case, an increase in predation by 30% would reduce the whitefly population by the same amount as an increase in parasitism by more than 75%. However, it is important to consider that life table data is specific to the pest, crop, and ecosystem. The more similar the production system is to the studied system, the more accurately the life table data would apply.

Predictions of pest pressure, made with life tables and pest development or movement models, can be overlaid on the production timeline. Comparing expected growth and development of crops and pests can influence decisions for preventative measures to be taken, establish pest monitoring methods and frequency, predict crop loss and risk, and decide on therapeutic measures and their implementation. Adjusting planting dates can be a simple change with a significant impact on crop production yields and required inputs.

Knowing the extent of tolerable damage to crops is needed to decide management strategies for pests. When used as a source of income, agricultural operations will often use an Economic Injury Levels (EIL) to set a tolerance threshold. In many private-use gardens, it can be difficult to calculate the “cost” of a tactic without the sale of a product.

When imperfections are tolerable, it may be more relevant to interpret “cost” as an estimate of labor requirements, environmental impact, and ability to meet initial production goals. If a main purpose of the garden is to be ornamental, the tolerance for damage and pests is likely low to zero. This tolerance will have a significant influence on preventative tactics, scouting, monitoring, and therapeutic tactics implemented.

Once the tolerance level is established for each pest, identify options for therapeutic strategies and tactics that are compatible with the total system. Only include those that the grower is willing to implement. Establish the specific conditions that would justify implementing each option, such as the detected date of the pest on a specific crop, population densities, stage of development of the crop and pest, etc. Once these parameters have been set for therapeutic options, preventative measures can be established. If done in reverse, therapeutic choices may contradict the pest prevention strategies. For example, preventative efforts are made to establish and develop natural enemy populations in anticipation of an annual diamondback moth (*Plutella xylostella*) migration. If the management plan calls for nonspecific chemical controls (i.e., plant essential oils) as a therapeutic tactic in response to feeding damage caused by the moth larvae, the preventative tactic is compromised. Therapeutic control may reduce the pest pressure, but it can decimate the natural enemy population, sometimes by a greater extent (Yi et al., 2007).

A scouting and monitoring program for pests, their predators, and crop development will be instrumental in the success of management practices. This will include deciding what life stage is most critical to manage for maximizing success and efficiency. In this program, include a format for recording event details and observations. The more data collected, the more useful it can be in evaluating the production plan and success of management strategies and tactics. However, data will only be collected if it is usable by the grower. It should be easily accessible and interpreted, and prepared before the start of the growing season.

Review and Revise

At this stage of the production plan, observations and soil sampling have been the only recommended actions in the garden. Again, review the proposed plan for compatibility between each decision within the system. Revise the plan when additional considerations or production challenges appear. Review necessary modifications to the system that will help achieve production and management goals, through maximizing productivity and minimizing negative impacts.

Implement the Production Plan

Finally, prepare the site for production in accordance with relevant preventative measures set by the production and pest management plans, and as possible with available resources. Potential site inadequacies would ideally have been identified during the initial system evaluation. Preventative measures for abiotic stresses would have been identified in the production plan and biotic stresses in the pest management plan. With much of the cognitive work completed before the growing season, less will be required at times of high physical labor by following the pre-established plan.

As the growing season finally begins, periodically update the production schedule with data from the daily log. Examples of valuable entries include daily temperature data, precipitation events and amounts (including supplemental irrigation), fertilizers applied (include nutritional components, rate, and volume), pest scouting, and monitoring results and estimates. An ideal log would include these data for each crop grown. Collected data can be used to update prediction models throughout the season to improve projections for crop growth and maturity. The production schedule can then be adjusted to account for any changes in predictions. With management options and requirements for implementing tactics already organized, the grower can reduce reaction times and focus more cognitive energy during the production season on scouting, monitoring, documenting, evaluating, predicting, critiquing, and improving the production system.

As an example in my own garden, I use microclimates to extend the harvest season for strawberries by at least two weeks, for a total harvest period of about five weeks. I have three strawberry patches. One is in full sun exposure, surrounded by hardscapes and easily watered. A second patch receives shade until mid-day, is surrounded by vegetation and can be watered with some effort. The third patch is in full shade and is difficult to water and access. The first patch is warmed early in the spring by the sun and hardscapes and receives water whenever it requires it. It flowers around two weeks before the second patch and is the most productive of the three with a harvest window of about two weeks. The main early-season pests in this patch are birds and my children; neither can resist the highly visible fruit at the first sight of color change. Once this patch begins to ripen, the fruit need picked every day as they quickly over-ripen in the heat and are infected by gray mold (*Botrytis cinerea*). The fruit that will not be eaten are removed so they are not a source of inoculum for the remaining fruit. Water is restricted during fruit ripening to reduce the hours of continuous wetness and minimize infection. The harvest window for the second patch begins just as the first is ending. Although these are all the same variety, the fruit from this patch are fewer, sweeter, and harvested over three weeks. The main pests in this patch are squirrels with little disease pressure. The third and neglected patch ripens the latest, has the lowest yield over the shortest window and has the sweetest fruit. It begins ripening around two weeks after the first patch is finished and lasts for only a week due to the low yield. The major pests in this patch are slugs, as there is always a dense layer of mulched leaves covering the ground to keep the soil surface moist. With supplemental water not required, the stems, leaves and fruit remain dry and are rarely infected by gray mold. If there was less tolerance for slug damage, the mulch could be removed for a period in the late summer, allowing the soil to dry out and reduce slug populations. Mulch could then be reapplied in the fall to retain soil-moisture through the fruiting season; thus, the low need for supplemental irrigation and few hours of continuous wetness are maintained to prevent gray mold. This is not a viable solution for controlling gray mold in the first patch, as much of the water received is from play activities that are a required use of the adjacent space.

Conclusion

A production system framework as presented in this document would best fit IPM Level III described by Norris et al. (2003). This ecosystem-level of integration is the most complex and likely achieved by few crop production systems. However, it is the ideal, and it is the duty of the environmental steward to constantly strive for this level of understanding. Consider as many interactions as possible within the production system, without becoming overwhelmed. Gradually build knowledge and experience. Whenever possible, evaluate the system and its ability to meet the needs and expectations of the stakeholders. The frequency of these reflections would ideally be at each stage in the production and planning process (system evaluation, production plan development, and implementation) and with each revolution of the plan. Think critically on the components, their compatibility with each other, and their impact within the entire system. With each revolution of the crop production plan, challenge assumptions. Through this process, we will gain capacity for understanding our socio-environmental systems to improve food resiliency.

REFERENCES

Agostini, F., Gregory, A. S., & Richter, G. M. (2015). Carbon Sequestration by Perennial Energy Crops: Is the Jury Still Out? *BioEnergy Research*, *8*(3), 1057–1080. https://doi.org/10.1007/s12155-014-9571-0

Alderson, P., & Rowland, M. (1989). Respiration. In *Making Use of Biology for GCSE* (pp. 53–63). Macmillan Education UK. https://doi.org/10.1007/978-1-349-10062-0_5

Alloway, B. J. (Ed.). (2013). *Heavy Metals in Soils* (Vol. 22). Springer Netherlands. https://doi.org/10.1007/978-94-007-4470-7

Alvarez, P. A., & Abud-Antún, A. J. (1995). Reporte de República Dominicana. *CEIBA*, *36*(1), 39–47.

Anjorin, O., Okpala, O., & Adeyemi, O. (2019). Coordinating Nigeria's micronutrient deficiency control programs is necessary to prevent deficiencies and toxicity risks. *Annals of the New York Academy of Sciences*, *1446*(1), 153–169. https://doi.org/10.1111/nyas.14055

APHA. (2013). *Improving Health and Wellness through Access to Nature [Policy No. 20137]* [Policy Statement]. American Public Health Association.

Armanda, D. T., Guinée, J. B., & Tukker, A. (2019). The second green revolution: Innovative urban agriculture's contribution to food security and sustainability – A review. *Global Food Security*, *22*, 13–24. https://doi.org/10.1016/j.gfs.2019.08.002

Ashley, J. M. (2016). *Food Security in the Developing World*. Academic Press. https://doi.org/10.1016/B978-0-12-801594-0.00008-7

Bennett, G., Young, E., Butler, I., & Coe, S. (2021). The Impact of Lockdown During the COVID-19 Outbreak on Dietary Habits in Various Population Groups: A Scoping Review. *Frontiers in Nutrition*, *8*, 626432. https://doi.org/10.3389/fnut.2021.626432

Beratan, K. K. (2007). A Cognition-based View of Decision Processes in Complex Social-Ecological Systems. *Ecology and Society*, *12*(1), Article 1. https://doi.org/10.5751/ES-02103-120127

Birgander, J., Rousk, J., & Olsson, P. A. (2017). Warmer winters increase the rhizosphere carbon flow to mycorrhizal fungi more than to other microorganisms in a temperate grassland. *Global Change Biology*, *23*(12), 5372–5382. https://doi.org/10.1111/gcb.13803

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability (Formerly: Journal of Personnel Evaluation in Education)*, *21*(1), 5. https://doi.org/10.1007/s11092-008-9068-5

Bledsoe, T. S., & Baskin, J. J. (2014). Recognizing Student Fear: The Elephant in the Classroom. *College Teaching*, *62*(1), 32–41. https://doi.org/10.1080/87567555.2013.831022

Boente, C., Matanzas, N., García-González, N., Rodríguez-Valdés, E., & Gallego, J. R. (2017). Trace elements of concern affecting urban agriculture in industrialized areas: A multivariate approach. *Chemosphere*, *183*, 546–556. https://doi.org/10.1016/j.chemosphere.2017.05.129

Bonfante, P., & Genre, A. (2010). Mechanisms underlying beneficial plant–fungus interactions in mycorrhizal symbiosis. *Nature Communications*, *1*(1), 48. https://doi.org/10.1038/ncomms1046

Brady, N. C., & Weil, R., R. (2002). *The Nature and Properties of Soils* (12th ed.). Prentice Hall.

Briggs, L., Trautmann, N., & Phillips, T. (2019). Exploring challenges and lessons learned in cross-cultural environmental education research. *Evaluation and Program Planning*, *73*, 156–162. https://doi.org/10.1016/j.evalprogplan.2019.01.001

Brouder, S. M., & Volenec, J. J. (2017). Chapter 20—Future climate change and plant macronutrient use efficiency. In M. A. Hossain, T. Kamiya, D. J. Burritt, L.-S. P. Tran, & T. Fujiwara (Eds.), *Plant Macronutrient Use Efficiency* (pp. 357–379). Academic Press. https://doi.org/10.1016/B978-0-12-811308-0.00020-X

Brown, G., & Desforges, C. (1977). PIAGETIAN PSYCHOLOGY AND EDUCATION: TIME FOR REVISION. *British Journal of Educational Psychology*, *47*(1), 7–17. https://doi.org/10.1111/j.2044-8279.1977.tb02995.x

Brown, M. K., Hershock, C., Finelli, C. J., & O'Neal, C. (2009). *Teaching for retention in science, engineering, and math disciplines: A guide for faculty [Occasional Paper 25]* (p. 12). Center for Research on Learning and Teaching, University of Michigan.

Brunner, R. D. (2006). A Paradigm for Practice. *Policy Sciences*, *39*(2), 135–167. https://doi.org/10.1007/s11077-006-9012-9

Bryant, T., & Reay-Jones, F. P. F. (2020). *Integrated Pest Management: Concepts and Strategies* (Fact Sheet LGP 1051; Agronomic Crops, p. 4). Land-Grant Press by Clemson Extension. https://lgpress.clemson.edu/publication/integrated-pest-management-concepts-and-strategies/

Carolan, M., & Hale, J. (2016). "Growing" communities with urban agriculture: Generating value above and below ground. *Community Development*, *47*(4), 530–545. https://doi.org/10.1080/15575330.2016.1158198

Cary, E. E., Grunes, D. L., Dallyn, S. L., Pearson, G. A., Peck, N. H., & Hulme, R. S. (1994). PLANT FE, AL AND CR CONCENTRATIONS IN VEGETABLES AS INFLUENCED BY SOIL INCLUSION. *Journal of Food Quality*, *17*(6), 467–476. https://doi.org/10.1111/j.1745-4557.1994.tb00167.x

Chabbi, A., Lehmann, J., Ciais, P., Loescher, H. W., Cotrufo, M. F., Don, A., SanClements, M., Schipper, L., Six, J., Smith, P., & Rumpel, C. (2017). Aligning agriculture and climate policy. *Nature Climate Change*, *7*(5), 307–309. https://doi.org/10.1038/nclimate3286

Cheng, L., Booker, F. L., Tu, C., Burkey, K. O., Zhou, L., Shew, H. D., Rufty, T. W., & Hu, S. (2012). Arbuscular Mycorrhizal Fungi Increase Organic Carbon Decomposition Under Elevated CO_2. *Science*, *337*(6098), 1084–1087. https://doi.org/10.1126/science.1224304

Chisi, M., & Peterson, G. (2019). Breeding and Agronomy. In *Sorghum and Millets* (pp. 23–50). Elsevier. https://doi.org/10.1016/B978-0-12-811527-5.00002-2

Costa, O. Y. A., Raaijmakers, J. M., & Kuramae, E. E. (2018). Microbial Extracellular Polymeric Substances: Ecological Function and Impact on Soil Aggregation. *Frontiers in Microbiology*, *9*, 1636. https://doi.org/10.3389/fmicb.2018.01636

Costello, C., Oveysi, Z., Dundar, B., & McGarvey, R. (2021). Assessment of the Effect of Urban Agriculture on Achieving a Localized Food System Centered on Chicago, IL Using Robust Optimization. *Environmental Science & Technology*, *55*(4), 2684–2694. https://doi.org/10.1021/acs.est.0c04118

Davis, J. G., & Whiting, D. (2013). *Choosing a Soil Amendment [Fact Sheet No. 7.235]* (Fact Sheet 7.235; Gardening Series, Basics). Colorado State University Extension.

Deng, X., Huang, N., & Yu, M. (2022). Cultural inclusion and social trust: Evidence from China. *Asian Journal of Social Science*, *50*(1), 16–26. https://doi.org/10.1016/j.ajss.2021.07.001

Dobermann, A., Bruulsema, T., Cakmak, I., Gerard, B., Majumdar, K., McLaughlin, M., Reidsma, P., Vanlauwe, B., Wollenberg, L., Zhang, F., & Zhang, X. (2022). Responsible plant nutrition: A new paradigm to support food system transformation. *Global Food Security*, *33*, 100636. https://doi.org/10.1016/j.gfs.2022.100636

Donovan, G. H., Butry, D. T., Michael, Y. L., Prestemon, J. P., Liebhold, A. M., Gatziolis, D., & Mao, M. Y. (2013). The Relationship Between Trees and Human Health: Evidence from the Spread of the Emerald Ash Borer. *American Journal of Preventive Medicine*, *44*(2), 139–145. https://doi.org/10.1016/j.amepre.2012.09.066

Drigo, B., Pijl, A. S., Duyts, H., Kielak, A. M., Gamper, H. A., Houtekamer, M. J., Boschker, H. T. S., Bodelier, P. L. E., Whiteley, A. S., Veen, J. A. van, & Kowalchuk, G. A. (2010). Shifting carbon flow from roots into associated microbial communities in response to elevated atmospheric CO_2. *Proceedings of the National Academy of Sciences*, *107*(24), 10938–10942. https://doi.org/10.1073/pnas.0912421107

Drijber, R. A., Doran, J. W., Parkhurst, A. M., & Lyon, D. J. (2000). Changes in soil microbial community structure with tillage under long-term wheat-fallow management. *Soil Biology and Biochemistry*, *32*(10), 1419–1430. https://doi.org/10.1016/S0038-0717(00)00060-2

Echevarría Icaza, L., & Van der Hoeven, F. (2017). Regionalist Principles to Reduce the Urban Heat Island Effect. *Sustainability*, *9*(5). https://doi.org/10.3390/su9050677

Eden, M., Bachmann, J., Cavalaris, C., Kostopoulou, S., Kozaiti, M., & Böttcher, J. (2020). Soil structure of a clay loam as affected by long-term tillage and residue management. *Soil and Tillage Research*, *204*, 104734. https://doi.org/10.1016/j.still.2020.104734

Egendorf, S. P., Cheng, Z., Deeb, M., Flores, V., Paltseva, A., Walsh, D., Groffman, P., & Mielke, H. W. (2018). Constructed soils for mitigating lead (Pb) exposure and promoting urban community gardening: The New York City Clean Soil Bank pilot study. *Landscape and Urban Planning*, *175*, 184–194. https://doi.org/10.1016/j.landurbplan.2018.03.012

Emery, M., & Flora, C. (2006). Spiraling-Up: Mapping Community Transformation with Community Capitals Framework. *Community Development*, *37*(1), 19–35. https://doi.org/10.1080/15575330609490152

EPA. (2011). *Urban Farm Business Plan* (Handbook EPA-905-K-11-002; Partnership for Sustainable Communities, p. 77). US EPA Region 5. https://www.epa.gov/sites/default/files/2015-10/documents/1.urban_farm_business_plan_handbook_091511_508.pdf

FAO. (2008). *An Introduction to the Basic Concepts of Food Security* (Food Security Information for Action: Practical Guides). EC-FAO Food Security Programme. www.foodsec.org/docs/concepts_guide.pdf

FAO, & WHO. (2017). *Fruit and vegetables for health initiative* (I6807EN/1/02.17; p. 8). FAO.

Fiallo-Olivé, E., Pan, L.-L., Liu, S.-S., & Navas-Castillo, J. (2020). Transmission of Begomoviruses and Other Whitefly-Borne Viruses: Dependence on the Vector Species. *Phytopathology®*, *110*(1), 10–17. https://doi.org/10.1094/PHYTO-07-19-0273-FI

Firman, D. M., & Allen, E. J. (2007). Chapter 33—Agronomic Practices. In D. Vreugdenhil, J. Bradshaw, C. Gebhardt, F. Govers, D. K. L. Mackerron, M. A. Taylor, & H. A. Ross (Eds.), *Potato Biology and Biotechnology* (pp. 719–738). Elsevier Science B.V. https://doi.org/10.1016/B978-044451018-1/50075-0

Garcia-Casal, M. N., Mowson, R., Rogers, L., Grajeda, R., & Groups, C. W. (2019). Risk of excessive intake of vitamins and minerals delivered through public health interventions: Objectives, results, conclusions of the meeting, and the way forward. *Annals of the New York Academy of Sciences*, *1446*(1), 5–20. https://doi.org/10.1111/nyas.13975

Glavan, M., Schmutz, U., Williams, S., Corsi, S., Monaco, F., Kneafsey, M., Rodriguez, P. A. G., Čenič-Istenič, M., & Pintar, M. (2018). The economic performance of urban gardening in three European cities – examples from Ljubljana, Milan and London. *Urban Forestry & Urban Greening*, *36*, 100–122. https://doi.org/10.1016/j.ufug.2018.10.009

Goldstein, B., Hauschild, M., Fernández, J., & Birkved, M. (2016). Testing the environmental performance of urban agriculture as a food supply in northern climates. *Journal of Cleaner Production*, *135*, 984–994. https://doi.org/10.1016/j.jclepro.2016.07.004

Gruba, P., & Mulder, J. (2015). Tree species affect cation exchange capacity (CEC) and cation binding properties of organic matter in acid forest soils. *Science of The Total Environment*, *511*, 655–662. https://doi.org/10.1016/j.scitotenv.2015.01.013

Gu, H., & Chou, C.-A. (2022). Optimizing non-uniform multivariate embedding for multiscale entropy analysis of complex systems. *Biomedical Signal Processing and Control*, *71*, 103206. https://doi.org/10.1016/j.bspc.2021.103206

Gubler, W. D., Rademacher, M. R., & Vasquez, S. J. (1999). Control of Powdery Mildew Using the UC Davis Powdery Mildew Risk Index. *APSnet Feature Articles*. https://doi.org/10.1094/APSnetFeature-1999-0199

Gupta, R., Anwer, M. M., & Sharma, Y. K. (2012). 15—Dill. In K. V. Peter (Ed.), *Handbook of Herbs and Spices (Second Edition)* (Second Edition, pp. 275–285). Woodhead Publishing. https://doi.org/10.1533/9780857095671.275

Hatfield, J. L., Sauer, T. J., & Cruse, R. M. (2017). *Chapter One—Soil: The Forgotten Piece of the Water, Food, Energy Nexus* (D. L. Sparks, Ed.; Vol. 143, pp. 1–46). Academic Press. https://doi.org/10.1016/bs.agron.2017.02.001

Heckman, J. R., Weil, R., & Magdoff, F. (2009). Practical Steps to Soil Fertility for Organic Agriculture. In C. Francis (Ed.), *Agronomy Monographs* (pp. 137–172). American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. https://doi.org/10.2134/agronmonogr54.c7

Hillel, D., Hatfield, J. L., Powlson, D. S., Rosenzweig, C., Scow, K. M., Singer, M. J., & Sparks, D. L. (Eds.). (2005). *Encyclopedia of soils in the environment* (1st ed, Vol. 3). Elsevier/Academic Press.

Hoorman, J. J., & Islam, R. (2010). *Understanding Soil Microbes and Nutrient Recycling* (Fact Sheet SAG-16; Agriculture and Natural Resources). The Ohio State University. https://ohioline.osu.edu/factsheet/SAG-16

Huber, D., Römheld, V., & Weinmann, M. (2012). Relationship between Nutrition, Plant Diseases and Pests. In *Marschner's Mineral Nutrition of Higher Plants* (pp. 283–298). Elsevier. https://doi.org/10.1016/B978-0-12-384905-2.00010-8

Inglett, P. W., Reddy, K. R., & Corstanje, R. (2005). Anaerobic Soils. In *Encylopedia of soils in the environment* (1st edition, Vol. 3, pp. 72–78). Elsevier/Academic Press.

Jacobs, A. A., Evans, R. S., Allison, J. K., Garner, E. R., Kingery, W. L., & McCulley, R. L. (2022). Cover crops and no-tillage reduce crop production costs and soil loss, compensating for lack of short-term soil quality improvement in a maize and soybean production system. *Soil and Tillage Research*, *218*, 105310. https://doi.org/10.1016/j.still.2021.105310

Jayatissa, R., & Fernando, D. N. (2019). Supplementation of micronutrients in children and food fortification initiatives in Sri Lanka: Benefits versus risks. *Annals of the New York Academy of Sciences*, *1446*(1), 139–152. https://doi.org/10.1111/nyas.13987

Jin, K., Shen, J., Ashton, R. W., Dodd, I. C., Parry, M. A. J., & Whalley, W. R. (2013). How do roots elongate in a structured soil? *Journal of Experimental Botany*, *64*(15), 4761–4777. https://doi.org/10.1093/jxb/ert286

Kempfert, H.-G., & Gebreselassie, B. (2006). 2—Material properties of soft soils. In *Excavations and Foundations in Soft Soils* (pp. 11–55). Springer-Verlag.

Kessler, R. (2013). Urban Gardening: Managing the Risks of Contaminated Soil. *Environmental Health Perspectives*, *121*(11–12), A326–A333. https://doi.org/10.1289/ehp.121-A326

Khan, A., Khan, S., Khan, M. A., Qamar, Z., & Waqas, M. (2015). The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and associated health risk: A review. *Environmental Science and Pollution Research*, *22*(18), 13772–13799. https://doi.org/10.1007/s11356-015-4881-0

Koncikowski, J., & Capozziello, N. (2021). Therapeutic gardening: A community-led, community-wide approach. *Acta Horticulturae*, *1330*, 31–40. https://doi.org/10.17660/ActaHortic.2021.1330.5

Kondo, M. C., Han, S., Donovan, G. H., & MacDonald, J. M. (2017). The association between urban trees and crime: Evidence from the spread of the emerald ash borer in Cincinnati. *Landscape and Urban Planning*, *157*, 193–199. https://doi.org/10.1016/j.landurbplan.2016.07.003

Kruse, J., Simon, J., & Rennenberg, H. (2013). Chapter 7—Soil Respiration and Soil Organic Matter Decomposition in Response to Climate Change. In R. Matyssek, N. Clarke, P. Cudlin, T. N. Mikkelsen, J.-P. Tuovinen, G. Wieser, & E. Paoletti (Eds.), *Climate Change, Air Pollution and Global Challenges* (Vol. 13, pp. 131–149). Elsevier. https://doi.org/10.1016/B978-0-08-098349-3.00007-4

Kuhn, T. S. (1970). (2nd ed.). University of Chicago Press.

Lehmann, J., & Kleber, M. (2015). The contentious nature of soil organic matter. *Nature*, *528*(7580), 60–68. https://doi.org/10.1038/nature16069

Liu, X., Lee Burras, C., Kravchenko, Y. S., Duran, A., Huffman, T., Morras, H., Studdert, G., Zhang, X., Cruse, R. M., & Yuan, X. (2012). Overview of Mollisols in the world: Distribution, land use and management. *Canadian Journal of Soil Science*, *92*(3), 383–402. https://doi.org/10.4141/cjss2010-058

Liu, Z., & Tran, K.-Q. (2021). A review on disposal and utilization of phytoremediation plants containing heavy metals. *Ecotoxicology and Environmental Safety*, *226*, 112821. https://doi.org/10.1016/j.ecoenv.2021.112821

Loker, A., & Wortman, S. E. (2021). The Vegetable Variety Navigator Decision-support Tool: An Interactive Visualization of Variety Trial Meta-analysis Results. *HortTechnology*, *31*(4), 535–541. https://doi.org/10.21273/HORTTECH04799-21

Ma, L. Q., Komar, K. M., Tu, C., Zhang, W., Cai, Y., & Kennelley, E. D. (2001). A fern that hyperaccumulates arsenic. *Nature*, *409*, 579. https://doi.org/10.1038/35078147

Maslo, B., & Lewis, C. (2013). *Strategies for Resident Canada Goose Control and Management in New Jersey* (Fact Sheet No. FS1217; Cooperative Extension, p. 4). Rutgers. https://njaes.rutgers.edu/fs1217/

Mattila, T. J., Hagelberg, E., Söderlund, S., & Joona, J. (2022). How farmers approach soil carbon sequestration? Lessons learned from 105 carbon-farming plans. *Soil and Tillage Research*, *215*, 105204. https://doi.org/10.1016/j.still.2021.105204

McBride, M. B., Shayler, H. A., Spliethoff, H. M., Mitchell, R. G., Marquez-Bravo, L. G., Ferenz, G. S., Russell-Anelli, J. M., Casey, L., & Bachman, S. (2014). Concentrations of lead, cadmium and barium in urban garden-grown vegetables: The impact of soil variables. *Environmental Pollution*, *194*, 254–261. https://doi.org/10.1016/j.envpol.2014.07.036

Minasny, B., & McBratney, A. B. (2018). Limited effect of organic matter on soil available water capacity. *European Journal of Soil Science*, *69*(1), 39–47. https://doi.org/10.1111/ejss.12475

Mishra, S., & Potischman, N. (2021). *Dietary Supplement Use Among Adults: United States,*. *399*, 8.

Mok, H.-F., Williamson, V. G., Grove, J. R., Burry, K., Barker, S. F., & Hamilton, A. J. (2014). Strawberry fields forever? Urban agriculture in developed countries: a review. *Agronomy for Sustainable Development*, *34*(1), 21–43. https://doi.org/10.1007/s13593-013-0156-7

Myers, D. G., & DeWall, C. N. (2018). *Psychology* (12^{th} ed.). Macmillan Learning.

Nagajyoti, P. C., Lee, K. D., & Sreekanth, T. V. M. (2010). Heavy metals, occurrence and toxicity for plants: A review. *Environmental Chemistry Letters*, *8*(3), 199–216. https://doi.org/10.1007/s10311-010-0297-8

Narango, D. L., Tallamy, D. W., & Marra, P. P. (2017). Native plants improve breeding and foraging habitat for an insectivorous bird. *Biological Conservation*, *213*, 42–50. https://doi.org/10.1016/j.biocon.2017.06.029

Naranjo, S. E., & Ellsworth, P. C. (2005). Mortality dynamics and population regulation in Bemisia tabaci. *Entomologia Experimentalis et Applicata*, *116*(2), 93–108. https://doi.org/10.1111/j.1570-7458.2005.00297.x

Norris, R. F., Caswell-Chen, E. P., & Kogan, M. (2003). *Concepts in integrated pest management*. Prentice Hall.

Nowak, D. J., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry & Urban Greening*, *4*(3), 115–123. https://doi.org/10.1016/j.ufug.2006.01.007

Nowak, D. J., Hirabayashi, S., Bodine, A., & Hoehn, R. (2013). Modeled PM2.5 removal by trees in ten U.S. cities and associated health effects. *Environmental Pollution*, *178*, 395–402. https://doi.org/10.1016/j.envpol.2013.03.050

Oladoye, P. O., Olowe, O. M., & Asemoloye, M. D. (2022). Phytoremediation technology and food security impacts of heavy metal contaminated soils: A review of literature. *Chemosphere*, *288*, 132555. https://doi.org/10.1016/j.chemosphere.2021.132555

Olum, S., Okello-Uma, I., A. Tumuhimbise, G., Taylor, D., & Ongeng, D. (2017). The Relationship between Cultural Norms and Food Security in the Karamoja Sub-Region of Uganda. *Journal of Food and Nutrition Research*, *5*(6), 427–435. https://doi.org/10.12691/jfnr-5-6-10

Ordiano-Flores, A., Galván-Magaña, F., & Rosiles-Martínez, R. (2011). Bioaccumulation of Mercury in Muscle Tissue of Yellowfin Tuna, Thunnus albacares, of the Eastern Pacific Ocean. *Biological Trace Element Research*, *144*(1–3), 606–620. https://doi.org/10.1007/s12011-011-9136-4

Pallardy, S. G. (2008). *Physiology of Woody Plants* (Third Edition). Academic Press. https://doi.org/10.1016/B978-012088765-1.50001-4

Paltseva, A. A., Cheng, Z., Egendorf, S. P., & Groffman, P. M. (2020). Remediation of an urban garden with elevated levels of soil contamination. *Science of The Total Environment*, *722*, 137965. https://doi.org/10.1016/j.scitotenv.2020.137965

Pedlowski, M. A., DA SILVA, V. A. C., CORABI ADELL, J. J., & HEYNEN, N. C. (2002). Urban forest and environmental inequality in Campos dos Goytacazes, Rio de Janeiro, Brazil. *Urban Ecosystems*, *6*(1–2), 9–20. https://doi.org/10.1023/A:1025910528583

Perez, J., Brown, M., & Miles, A. (Eds.). (2015). *Teaching Direct Marketing & Small Farm Viability* (2nd ed.). Center for Agroecology & Sustainable Food Systems. https://agroecology.ucsc.edu/about/publications/Teaching-Direct-Marketing/units-1-9.html

Petit, J. C. J., Maggi, P., Pirard, C., Charlier, C., Ruttens, A., Liénard, A., Colinet, G., & Remy, S. (2022). Human biomonitoring survey (Pb, Cd, As, Cu, Zn, Mo) for urban gardeners exposed to metal contaminated soils. *Environmental Pollution*, *312*(120028). https://doi.org/10.1016/j.envpol.2022.120028

Pilbeam, D. J. (2015). Breeding crops for improved mineral nutrition under climate change conditions. *Journal of Experimental Botany*, *66*(12), 3511–3521. https://doi.org/10.1093/jxb/eru539

Poulsen, M. N., McNab, P. R., Clayton, M. L., & Neff, R. A. (2015). A systematic review of urban agriculture and food security impacts in low-income countries. *Food Policy*, *55*, 131–146. https://doi.org/10.1016/j.foodpol.2015.07.002

Powell, J. P., & Reinhard, S. (2016). Measuring the effects of extreme weather events on yields. *Weather and Climate Extremes*, *12*, 69–79. https://doi.org/10.1016/j.wace.2016.02.003

Prial, D. (2019). *Community Supported Agriculture* (Publication No. IP584; ATTRA Sustainable Agriculture, p. 16). NCAT. https://attra.ncat.org/publication/community-supported-agriculture/

Rahman, F., & Naidu, R. (2009). The influence of arsenic speciation (AsIII & AsV) and concentration on the growth, uptake and translocation of arsenic in vegetable crops (silverbeet and amaranth): Greenhouse study. *Environmental Geochemistry and Health*, *31*(S1), 115–124. https://doi.org/10.1007/s10653-008-9241-2

Reed, M. S. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation*, *141*(10), 2417–2431. https://doi.org/10.1016/j.biocon.2008.07.014

Relf, P. D. (2021). Collaboration is the key to expanding health and life quality through horticulture. *Acta Horticulturae*, *1330*, 115–132. https://doi.org/10.17660/ActaHortic.2021.1330.13

Rodríguez-Eugenio, N., McLaughlin, M., & Pennock, D. (2018). *Soil pollution: A hidden reality*. FAO.

Saha, M., & Eckelman, M. J. (2017). Growing fresh fruits and vegetables in an urban landscape: A geospatial assessment of ground level and rooftop urban agriculture potential in Boston, USA. *Landscape and Urban Planning*, *165*, 130–141. https://doi.org/10.1016/j.landurbplan.2017.04.015

Saleem, M., Pervaiz, Z. H., Contreras, J., Lindenberger, J. H., Hupp, B. M., Chen, D., Zhang, Q., Wang, C., Iqbal, J., & Twigg, P. (2020). Cover crop diversity improves multiple soil properties via altering root architectural traits. *Rhizosphere*, *16*, 100248. https://doi.org/10.1016/j.rhisph.2020.100248

Sarda, B., Delamaire, C., Serry, A.-J., & Ducrot, P. (2022). Changes in home cooking and culinary practices among the French population during the COVID-19 lockdown. *Appetite*, *168*, 105743. https://doi.org/10.1016/j.appet.2021.105743

Shaheb, M. R., Venkatesh, R., & Shearer, S. A. (2021). A Review on the Effect of Soil Compaction and its Management for Sustainable Crop Production. *Journal of Biosystems Engineering*, *46*(4), 417–439. https://doi.org/10.1007/s42853-021-00117-7

Shen, X., Dai, M., Yang, J., Sun, L., Tan, X., Peng, C., Ali, I., & Naz, I. (2022). A critical review on the phytoremediation of heavy metals from environment: Performance and challenges. *Chemosphere*, *291*, 132979. https://doi.org/10.1016/j.chemosphere.2021.132979

Shewfelt, R. L. (2017). How Does Food Processing Change the Nutritional Value of Foods? In R. L. Shewfelt, *In Defense of Processed Food* (pp. 107–123). Springer International Publishing. https://doi.org/10.1007/978-3-319-45394-1_7

Six, J., Bossuyt, H., Degryze, S., & Denef, K. (2004). A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. *Soil and Tillage Research*, *79*(1), 7–31. https://doi.org/10.1016/j.still.2004.03.008

Smith, E. R., & DeCoster, J. (2000). Dual-Process Models in Social and Cognitive Psychology: Conceptual Integration and Links to Underlying Memory Systems. *Personality and Social Psychology Review*, *4*(2), 108–131. https://doi.org/10.1207/S15327957PSPR0402_01

Smith, P., Gregory, P. J., van Vuuren, D., Obersteiner, M., Havlík, P., Rounsevell, M., Woods, J., Stehfest, E., & Bellarby, J. (2010). Competition for land. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 2941–2957. https://doi.org/10.1098/rstb.2010.0127

Soil Survey Staff. (1999). *Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys.* (2nd ed., Issue 436). Natural Resources Conservation Service. https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/class/taxonomy/

Sparks, D. L. (2003a). 4—Soil Solution-Solid Phase Equilibria. In D. L. Sparks (Ed.), *Environmental Soil Chemistry* (2nd ed., pp. 115–132). Academic Press. https://doi.org/10.1016/B978-012656446-4/50004-9

Sparks, D. L. (2003b). 5—Sorption Phenomena on Soils. In D. L. Sparks (Ed.), *Environmental Soil Chemistry* (2nd ed., pp. 133–186). Academic Press. https://doi.org/10.1016/B978-012656446-4/50005-0

Sparks, D. L. (2003c). *Environmental Soil Chemistry* (2nd ed.). Academic Press. https://doi.org/10.1016/B978-0-12-656446-4.X5000-2

Streich, A. M., Mamo, M., Wortmann, C. S., Blanco, H., & McCallister, D. L. (2013). *Properties of Landscape Soils [Fact Sheet EC1267]* (Extension Circular, p. 16) [Fact Sheet]. University of Nebraska-Lincoln Extension, Institute of Agruculture and Natural Resources.

Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. S. (Eds.). (2015). *Plant physiology and development* (6th ed.). Sinauer Associates, Inc., Publishers.

Tang, W.-W., Zeng, G.-M., Gong, J.-L., Liang, J., Xu, P., Zhang, C., & Huang, B.-B. (2014). Impact of humic/fulvic acid on the removal of heavy metals from aqueous solutions using nanomaterials: A review. *Science of The Total Environment*, *468–469*, 1014–1027. https://doi.org/10.1016/j.scitotenv.2013.09.044

Taub, D. R., Miller, B., & Allen, H. (2008). Effects of elevated CO_2 on the protein concentration of food crops: A meta-analysis. *Global Change Biology*, *14*(3), 565–575. https://doi.org/10.1111/j.1365-2486.2007.01511.x

Thistlewood, H. M. A., & Judd, G. J. R. (2019). Twenty-five Years of Research Experience with the Sterile Insect Technique and Area-Wide Management of Codling Moth, Cydia pomonella (L.), in Canada. *Insects*, *10*(9), 292. https://doi.org/10.3390/insects10090292

Thompson, R. (2018). Gardening for health: A regular dose of gardening. *Clinical Medicine*, *18*(3), 201–205. https://doi.org/10.7861/clinmedicine.18-3-201

Trivedi, P., Singh, B. P., & Singh, B. K. (2018). Chapter 1—Soil Carbon: Introduction, Importance, Status, Threat, and Mitigation. In B. K. Singh (Ed.), *Soil Carbon Storage* (pp. 1–28). Academic Press. https://doi.org/10.1016/B978-0-12-812766-7.00001-9

UC IPM. (2016, June 21). *How to Manage Pests, Degree-Days*. University of California Agriculture & Natural Resources. http://www.ipm.ucdavis.edu/WEATHER/ddconcepts.html#ipmpagetop

United Nations, Department of Economic and Social Affairs, & Population Division. (2018). *World urbanization prospects: The 2018 revision [key facts]*. United Nations. https://population.un.org/wup/Publications/

United Nations, & Population Division. (2020). *Urban population (% of total population)* (World Urbanization Prospects: 2018 Revision). United Nations, Population Division. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=US-1W

US EPA. (2001). 40 CFR Part 745: Lead; Identification of Dangerous Levels of Lead; Final Rule. In *Federal Register* (Vol. 66, pp. 1205–1240). Office of the Federal Register, National Archives and Records Administration. https://www.govinfo.gov/app/details/FR-2001-01-05/01-84

US EPA. (2007). *The Use of Soil Amendments for Remediation, Revitalization, and Reuse* (EPA 542-R-07-013; p. 52). EPA. https://www.epa.gov/biosolids/use-soil-amendments-remediation-revitalization-and-reuse

US EPA. (2011). *Brownfields and Urban Agriculture: Interim Guidelines for Safe Gardening Practices* (EPA 560/S-11/001; p. 24). Region 5 Superfund Division, Environmental Protection Agency. http://www.epa.gov/swerosps/bf/urbanag/pdf/bf_urban_ag.pdf

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 Groenigen, K. J., Osenberg, C. W., Terrer, C., Carrillo, Y., Dijkstra, F. A., Heath, J., Nie, M., Pendall, E., Phillips, R. P., & Hungate, B. A. (2017). Faster turnover of new soil carbon inputs under increased atmospheric CO2. *Global Change Biology*, *23*(10), 4420–4429. https://doi.org/10.1111/gcb.13752

van Oort, P. A. J., Timmermans, B. G. H., Schils, R. L. M., & van Eekeren, N. (2023). Recent weather extremes and their impact on crop yields of the Netherlands. *European Journal of Agronomy*, *142*, 126662. https://doi.org/10.1016/j.eja.2022.126662

van Tilburg, A. J., & Hudson, P. F. (2022). Extreme weather events and farmer adaptation in Zeeland, the Netherlands: A European climate change case study from the Rhine delta. *Science of The Total Environment*, *844*, 157212. https://doi.org/10.1016/j.scitotenv.2022.157212

Walsh, D., Glass, K., Morris, S., Zhang, H., McRae, I., Anderson, N., Alfieri, A., Egendorf, S. P., Holberton, S., Owrang, S., & Cheng, Z. (2018). Sediment exchange to mitigate pollutant exposure in urban soil. *Journal of Environmental Management*, *214*, 354–361. https://doi.org/10.1016/j.jenvman.2018.03.013

Wang, R., Bowling, L. C., & Cherkauer, K. A. (2016). Estimation of the effects of climate variability on crop yield in the Midwest USA. *Agricultural and Forest Meteorology*, *216*, 141–156. https://doi.org/10.1016/j.agrformet.2015.10.001

White, P. J., & Brown, P. H. (2010). Plant nutrition for sustainable development and global health. *Annals of Botany*, *105*(7), 1073–1080. https://doi.org/10.1093/aob/mcq085

Whitmarsh, L., & Corner, A. (2017). Tools for a new climate conversation: A mixed-methods study of language for public engagement across the political spectrum. *Global Environmental Change*, *42*, 122–135. https://doi.org/10.1016/j.gloenvcha.2016.12.008

Widdig, M., Schleuss, P.-M., Biederman, L. A., Borer, E. T., Crawley, M. J., Kirkman, K. P., Seabloom, E. W., Wragg, P. D., & Spohn, M. (2020). Microbial carbon use efficiency in grassland soils subjected to nitrogen and phosphorus additions. *Soil Biology and Biochemistry*, *146*, 107815. https://doi.org/10.1016/j.soilbio.2020.107815

Wolsko, C., Ariceaga, H., & Seiden, J. (2016). Red, white, and blue enough to be green: Effects of moral framing on climate change attitudes and conservation behaviors. *Journal of Experimental Social Psychology*, *65*, 7–19. https://doi.org/10.1016/j.jesp.2016.02.005

Yang, L., Wang, J., Yang, Y., Li, S., Wang, T., Oleksak, P., Chrienova, Z., Wu, Q., Nepovimova, E., Zhang, X., & Kuca, K. (2022). Phytoremediation of heavy metal pollution: Hotspots and future prospects. *Ecotoxicology and Environmental Safety*, *234*, 113403. https://doi.org/10.1016/j.ecoenv.2022.113403

Yang, Q., Xu, Y., Liu, S., He, J., & Long, F. (2011). Concentration and potential health risk of heavy metals in market vegetables in Chongqing, China. *Ecotoxicology and Environmental Safety*, *74*(6), 1664–1669. https://doi.org/10.1016/j.ecoenv.2011.05.006

Yi, C.-G., Kwon, M., Hieu, T. T., Jang, Y.-S., & Ahn, Y.-J. (2007). Fumigant Toxicity of Plant Essential Oils to Plutella xylostella (Lepidoptera: Yponomeutidae) and Cotesia glomerata (Hymenoptera: Braconidae). *Journal of Asia-Pacific Entomology*, *10*(2), 157–163. https://doi.org/10.1016/S1226-8615(08)60347-7

Young, J. C., Searle, K., Butler, A., Simmons, P., Watt, A. D., & Jordan, A. (2016). The role of trust in the resolution of conservation conflicts. *Biological Conservation*, *195*, 196–202. https://doi.org/10.1016/j.biocon.2015.12.030

Zhang, J. W., Piff, P. K., Iyer, R., Koleva, S., & Keltner, D. (2014). An occasion for unselfing: Beautiful nature leads to prosociality. *Journal of Environmental Psychology*, *37*, 61–72. https://doi.org/10.1016/j.jenvp.2013.11.008

Zhang, Z., & Peng, X. (2021). Bio-tillage: A new perspective for sustainable agriculture. *Soil and Tillage Research*, *206*, 104844. https://doi.org/10.1016/j.still.2020.104844

Zheng, F., Wu, X., Zhang, M., Liu, X., Song, X., Lu, J., Wang, B., Groenigen, K. J. van, & Li, S. (2022). Linking soil microbial community traits and organic carbon accumulation rate under long-term conservation tillage practices. *Soil and Tillage Research*, *220*, 105360. https://doi.org/10.1016/j.still.2022.105360

Zhou, H., Yang, W.-T., Zhou, X., Liu, L., Gu, J.-F., Wang, W.-L., Zou, J.-L., Tian, T., Peng, P.-Q., & Liao, B.-H. (2016). Accumulation of Heavy Metals in Vegetable Species Planted in Contaminated Soils and the Health Risk Assessment. *International Journal of Environmental Research and Public Health*, *13*(3), 289. https://doi.org/10.3390/ijerph13030289

Zoecklein, B. W., & Gump, B. H. (2022). Practical methods of evaluating grape quality and quality potential. In *Managing Wine Quality* (pp. 135–185). Elsevier. https://doi.org/10.1016/B978-0-08-102067-8.00003-8