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URBAN PERMACULTURE FOR CLIMATE-RESILIENT FARMING IN WORCESTER, MASSACHUSETTS

PRIYANKA SHRESTHA

JUNE 2021

A Practitioner Paper

Submitted to the faculty of Clark University, Worcester, Massachusetts, in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science & Policy in the department of International Development, Community & Environment (IDCE)

And accepted on the recommendation of

Morgan Ruelle, Chief Instructor

ABSTRACT

URBAN PERMACULTURE FOR CLIMATE-RESILIENT FARMING IN WORCESTER, MASSACHUSETTS

PRIYANKA SHRESTHA

Climate changes observed over the past several decades are associated with changes in the multiple components of hydrological systems, including changes in precipitation patterns, higher rates of evaporation and increasing soil erosion. In 2019, the city of Worcester declared a climate emergency, stating that climate change threatens the community's environment. Permaculture can strengthen crucial relationships between nature and human beings, offering long-lasting solutions to protect our planet from risks associated with climate change. This paper focuses on the application of permaculture practices in urban agriculture, including techniques to address changes in hydrological systems. Use of perennial plants, creating swales, drip irrigation, and *hügelkultur* are practices that could help communities and environmental organizations adapt to climate change and promote local food security. The goal of this paper is to introduce the concept of permaculture and support its application in urban gardens and farms facing the challenges of water variability due to climate change.

Morgan Ruelle, Ph.D.
Chief Instructor

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ACADEMIC HISTORY

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INTRODUCTION

"Vision is not seeing things as they are but as they will be."- This proverb emphasizes the importance of understanding the current issues with a futuristic vision and the ability to see beyond the present (Holmgren, 2020). On that scope, the availability of water resources for consumption and ecosystems highly relies on the spatiotemporal distribution of precipitation (Seddon et al., 2016). Consequences of variability in the water sources due to climate change, therefore, results in fluctuation in water availability, which has major implications for the ecosystem and entire biosphere (Haddeland et al., 2014). Several studies have examined the alteration of precipitation and evaporation patterns and their characteristics. Results show that variation in the combination of monthly evaporation and precipitation due to climate change has a wider implication for regional hydrology, biodiversity, ecology, and crop yield (Gornall et al., 2010). While several institutions have been closely studying the adverse effects of worldwide changes with regards to the fluctuation of water systems due to climate variables, there is room for more assessment and research (D.C. et al., 2011). Thus, there is a dire need to understand water systems and come up with climate-resilient practices on a smaller scale with individual effort.

The subject of detrimental environmental change due to the changing climate has been a major concern. Among the several unprecedented challenges that climate change poses, the availability of quality water and soil for agriculture is amongst the most crucial ones that require attention (Nhemachena et al., 2020). The sensitivity of crop productivity to the changing climate conditions will accelerate more with increased variability in the availability of water resources and extreme events such as drought (Nhemachena et al., 2020). Both seasonal scarcity or overabundance of water affects the productivity and growth of crops, subsequently giving rise to a scarcity of food produced and ultimately, hunger (Wheeler & von Braun, 2013). Agriculture is most likely going to be one of the hardest-hit sectors on a global scale (Wheeler & von Braun, 2013). According to the Environmental Protection Agency (EPA), climate change is most likely to have a greater impact on food security at both regional and local levels in the United States (Brown et al., 2015). It is important to anticipate the adverse effects of the changing environment and take appropriate measures to minimize the risks it can instigate. The future of climate adaptation will depend on recognizing the fact that it is a shared responsibility - from an organizational level to an individual effort - where each has its complementary role to play.

There is a substantial number of scientific discoveries and agreement around the subject of climate change. Reports published by IPCC show that impacts of climate change in the present will continue in the future in several different ways such as extreme events, fluctuating patterns of precipitation, droughts and its potential damage to public health, displacement, food insecurity, etc. (IPCC, 2018). This has reiterated the need to closely understand the relationship of organisms within a system and adopt sustainable measures and designs that will help better equip and prepare communities for the years ahead (Alvar-Beltrán et al., 2020). Permaculture, which ensures the sustainable philosophy of life with its ethical and scientific designs, introduces one of those concepts whose inherent mechanism is to understand the natural pattern and incorporate those practices in achieving the goals of sustainability (Verma & Tiwari, 2020).

Nature and ecosystems are like sculptures and art that create links between living systems that depend on each other (Sascha, 2000). Every ecosystem with living beings - be it in the water or land is connected and interlinked - up, down, and underground. It is fascinating to see how - from the smallest microbes fixing nitrogen in the soil to a lion preying on its food for dinner in the forest – all organisms are connected. They tend to find a pattern, a complex web to support and sustain one another. The entangled web of the food chain and nature's way of working itself has so many important lessons that we can learn. The basic principle of permaculture expresses and discovers these natural patterns, advocates advancement in the daily choices and habits of human life systems that are not only based on natural ecosystems but the beliefs and values that people hold concerning nurturing of earth, animals, fishes, birds, while also sensibly utilizing the available natural resources as well as adapting to the ever-changing nature of the environment (Krebs & Bach, 2018). The future of climate adaptation will depend on recognizing the fact that it is a shared responsibility to protect nature. Therefore, I propose in this paper that increasing the capacity of the resources available within our communities will better prepare us for the future and make us more resilient towards the change that we will be seeing in the coming years. I introduce the concepts and techniques of permaculture that can be used as an adaptation measure in urban farms in Worcester, focusing mainly on the conservation and sustainability of these farms in terms of water conservation.

This paper will begin by giving readers a brief background on the origin of the project, followed by a brief introduction to the organization that hosted my internship, the Regional Environmental Council (REC), including who they are and what do they do for urban farms. I will then talk about permaculture and its twelve principles; its history, concepts, techniques, and recognition in the agriculture world, followed by the history of urban farming in Massachusetts and climate change impacts on water availability. I will go on to introduce a permaculture practice known as xeriscaping and its four components, describing their practicality and effectiveness. Lastly, the recommendation section will draw out some key points from the paper and include suggestions related to this research, addressing some knowledge gaps and permaculture practices that could potentially be used by institutions, organizations, communities, and individuals in Worcester. The overall goal of this paper is to incorporate the concept of permaculture and implement them on urban farms that could potentially face the challenges of water variability due to climate change in the future.

BACKGROUND

Origin of the paper

My journey on the path of becoming an environmentalist started at the early age of 18, when I decided to get a degree in Environmental Science. I committed to a four-year study in the field and worked in two different non-profits before I graduated to understand the grassroots approach to the issues of climate change. Fast-forwarding to my first year in the United States as a graduate student in Environmental Science and Policy at Clark University, I had the opportunity to explore vast areas of subjects that I was interested in. The department of International Development, Community and Environment, as the name goes, incorporated a multidisciplinary approach to our courses, opens opportunities to explore in one’s career and interests in the field. One such course was “Science Meets Policy”, which introduced me to a wide range of topics, but one that stood out for me was incorporating climate resilience in farming and agriculture. I felt myself growing interested in knowing more about the importance of agriculture and food security in less privileged communities that had limited access to healthy food. However, I had negligible experience in the field of agriculture, as my past practical experience centered around environmental advocacy and climate justice.

In July 2020, amidst the pandemic, I was offered a part-time job at the Regional Environmental Council (REC) as a Volunteer Engagement Specialist, an organization that works for food security in Worcester. I was thrilled to have been offered my first job in the United States and felt exhilarated to have been given an opportunity to expand my knowledge and experience in the field. As excited as I was for the opportunity, I was equally nervous, as I had very little experience and knowledge in the field of food security, urban farming, and agriculture. I did have a year of experience working at an advocacy firm for environmental justice that helped me see the value of the grassroots movement and the significance it holds in the community. This position served as an opportunity for me to advance my skills, instigate the desire to be more proactive, and create every little impact I could at a local scale. My work as an intern in the organization involved several site visits to urban farms around the Main South neighborhood in Worcester, shadowing and assisting my supervisor at REC. I was introduced to permaculture by my supervisor and one of my colleagues as they were already incorporating some of its techniques in these urban farms and gardens. I familiarized myself with the term and started digging in deeper about what it truly meant. I grew curious as to how a theoretical concept could be applicable in an urban setting. As I started doing my research and subsequently continued visiting sites, meeting new people, and having conversations around some challenges that farmers had faced in recent years, an issue that caught my attention was the fluctuation in the water patterns over the past few summers. To confirm this observation, I went to the National Weather Service website, only to find out that the government had declared a second-level drought emergency in Worcester. As outlined by the Massachusetts Drought Management Plan, second-level drought is the level of severity in which the state faces significant dryness with potential impacts such as crop loss and water scarcity in communities. To tackle those issues, state and federal agencies government implement more stringent watering restrictions (EEA, 2020). To understand the severity of this situation, I felt it was essential to expand my understanding and knowledge in this area that could potentially create more challenges in the future, and I finally decided to conduct secondary research and draw out some useful practices that could be used in these farms to better adapt to the issues of seasonal water scarcity or flooding with the help of permaculture designs.

The Regional Environmental Council (REC)

My journey on this project began with working for REC, therefore I want to begin by giving readers a brief background on REC, an organization that has spent over 50 years working on food security and has been a major inspiration for this paper. REC is a grassroots environmental justice organization that was founded in 1971 with a mission to build healthy, sustainable, and equitable communities in Worcester (REC, 2019). Over these years, REC has built its food justice program strong enough to be highly recognized within Worcester. It has been successful in promoting community leadership and reaching out to food insecure communities in Worcester through its various programs.

REC's efforts are focused around four major areas: 1) a community garden network that is watched over by UGROW, 2) professional development skills and youth development through urban agriculture mentorship and volunteerism by YOUTHGROW, 3) farmers market and mobile market to address healthy food habits, 4) promote organic food and offer support to eradicate food insecurity in the community through food pantries at Worcester Regional Food Hub. I was working for UGROW, which manages the network of community gardens and farms in the Main South neighborhood. UGROW was established as an alternative to corporate agriculture to encourage agriculture and gardening in an urban setting that would eventually strengthen and beautify the local environment, also promoting healthy urban gardening in the locality. Today, the network helps and maintains over 60 community urban gardens including school gardens, backyard gardens, and community farms (REC, 2019).

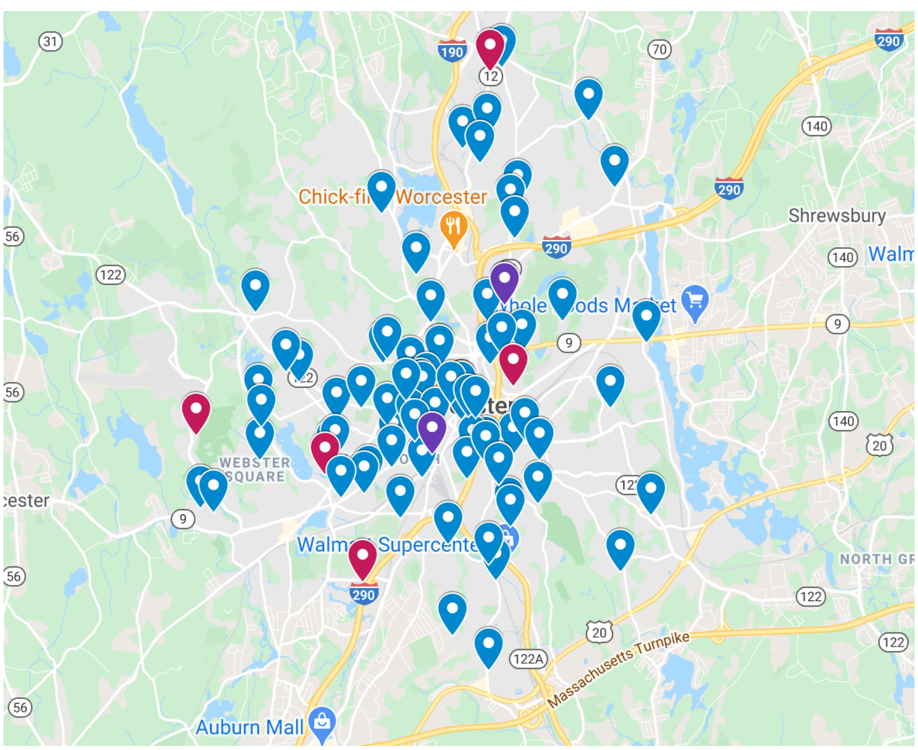

Figure 1. Urban gardens managed by the Regional Environmental Council (Knudson, Clark University, 2020)

REC develops and coordinates workshops and events that bring people who are passionate about the environment together to address issues of environmental justice in the community. It gives the local communities a platform to act upon the issues of food justice. It provides events and forums for residents around the neighborhood and encourages food justice education, networking, problem-solving and visioning, and healthy community building in Worcester and beyond. The organization's belief in advocacy at the local, state, and federal level is strong, which additionally works to push public policies that foster food and social justice for healthy neighborhoods, schools, and workplaces. REC has been able to successfully establish itself as a grassroots food justice organization due to its expertise in supporting urban agriculture and its passion to serve and educate the local communities about the importance of healthy food systems. Its biggest strength lies in its values towards relationship and community building. It promotes self-reliance and resilience in the farms and gardens it manages, which provides support to the residents and gardeners to receive healthy food in Worcester.

Urban agriculture and its significance

Urban agriculture can be defined as a unique form of agriculture that enables growing crops and other plants throughout urban and peri-urban areas, mostly by applying intensive production methods (Pearson et al., 2010). In a broader term, farms adapted to small urban spaces that allow the growing of plants, further creating markets for local products, is defined as urban agriculture (Gerritt et al., 2007). Urban agriculture usually entails two major efforts, the first being small-scale urban farming or gardening that are mostly school or community gardens. They are oftentimes utilized for educational purposes and can have positive social impacts on the communities and surrounding neighborhoods. The second effort is larger scale, targeting larger cultivation and production. Even though these are smaller than the farms in rural areas, they are still large in an urban setting.

Popularity and interest in urban agriculture have been rapidly increasing in recent years. This is due to the increase in awareness among communities about local food production as well as health concerns. Urban agriculture is perceived as a multifaceted program that generates several benefits including more community involvement and engagement, access to organic food, culturally diverse food, educational opportunities, environmentally conscious farming practices, urban greening, etc. (Pearson et al., 2010).

PERMACULTURE

The definition of permaculture is broad and can be subjective; however, in its simplest and the most original form, Bill Mollison coined permaculture as “a philosophy of functioning with, rather than against nature; of prolonged and solicitous observation rather than extended and inconsiderate labor; of looking at flora and fauna in all their functions, rather than care for any vicinity as a single-product system” (Akhtar et al., 2016, p. 32). The term “permaculture” is an abbreviation of the words ‘permanent’, ‘agriculture’ and ‘culture’ (Veteto & Lockyer, 2008). The concept and practices advocated by permaculture are inspired by nature’s self-resilient and self-sustainable patterns of balancing its system and extending agriculture, farming practices, and techniques towards sustainability. The idea of permaculture is to use principles that are grounded in the beliefs and values of modern culture, the science of ecology, and landscape geography. Based upon these principles, permaculture practices can be extended and used in several fields such as urban farming, regenerative agriculture, and community resilience (Veteto & Lockyer, 2008).

For many people, the concept of permaculture is so broad that it’s often misinterpreted as a skill or design itself and its usefulness is often reduced because of its global scope (Holmgren, 2020). To break down the concept more simply and understandably, I’ll be describing the basic concept of permaculture in the way the co-originator of permaculture, David Holmgren, describes it in his paper “Essence of Permaculture” (Holmgren, 2020). Permaculture is a framework and a vision that gives a foundational design and idea for individuals and communities to incorporate into their own life or lifestyle. It is not a landscape, regenerative farm, energy-efficient building, or skills that can be used in organic gardens. Instead, its concepts can be used to create designs, techniques, patterns, and manage all those things to achieve sustainable cities and future. Another important aspect of permaculture is the network. The concept of a network refers to individuals and groups who are implementing, spreading awareness, and educating people and communities on permaculture design principles. These groups are comprised of students, adults gardening in their backyards, and farmers. As a concept that emphasizes small-scale impacts and changes, these permaculture practitioners are creating changes at the local level that directly or indirectly influence organic urban farming. It’s been over 30 years that several permaculture design courses have been driving permaculture training and inspiring people worldwide. The increased popularity of permaculture design has encouraged about 100,000 trained permaculture practitioners to offer semi-structured permaculture design courses all over the world (Veteto & Lockyer, 2008). Likewise, permaculture strategies actively seek or create opportunities in communities that encourage building self-reliance and community values. Even though sustainable production has been a key objective in permaculture approaches and strategies, its effect can be seen in sustainable consumption. The conceptual framework that permaculture is based upon is deeply rooted in the ecological sciences; however, it iss crucial to understand that its potential has evolved over the years, developing a holistic design process for complex ecosystems, and contributing to the advancement of the culture of sustainability through innovative and practical solutions and approaches to offset excessive use of resources.

In the above paragraph, I introduced a broad idea and concept behind permaculture. We now move to narrow the scope down to the implementation of these concepts in the real world, with real designs. Permaculture’s ecological systems and designs were first introduced by the ecologist H. T. Odum (Zari, 2012). Odum perceived the networks of energy flows, its storage, and transformation in a natural system like an electric circuit – intertwined and interconnected. Odum incorporated a thermodynamics perspective to his framework of permaculture designs, creating a system that could be modeled and diagrammed (Zari, 2012). Permaculture recognizes that land-use systems on Earth are never separate entities from social systems, so these two should not be viewed apart. The concept of permaculture incorporates the roots of both with design systems, landscapes, and their relationship with species that are sustainable socio-ecological land-use systems. Odum argued that species are again interchangeable system components, which by nature are distinct but are resourceful to design novel and productive ecosystems (Zari, 2012). The popular idea of seeding a diverse group of plants in the farm comes from this very concept of valuing the inputs and outputs of species that creates unique assemblages, transforming and exchanging energy between themselves, minimizing or even substituting material input and human labor (Ferguson & Lovell, 2014). In this view, permaculture has several branches including ecological design, engineering, environmental design, and construction. It integrates these concepts and creates self-maintained habitats and agricultural systems modeled from natural ecosystems (Frank et al., 2015). However, three basic ethical norms help construct these frameworks: care for the earth, care for the people, and twelve permaculture principles that limit production, consumption, and redistribution of surplus. I will introduce the twelve principles of permaculture in more depth in the coming paragraphs.

Permaculture is one of the most radical practices for self-sustainable and climate-resilient agriculture in an urban setting. According to the United Nations, by the year 2050, approximately 68% of the global population will be living in cities (UN DESA, 2018). The implication of these statistics could be staggering for both economy and environment. It would typically mean cities would be resource and energy-intensive, which would require a large amount of food, water, and natural resources to provide communities. To meet those demands, cities must establish systems that are sustainable and reliable. Urban areas could be self-sustainable and utilize existing resources efficiently by implementing permaculture designs.

Principles of permaculture

In this section, I will be summarizing the 12 principles of Permaculture based on the book *Permaculture: Principles and Pathways Beyond Sustainability* by David Holmgren, 2020. This will give readers a deeper and broader idea of the key concepts and values of the permaculture system.

The techniques and concept of permaculture encourage creating resilient living systems that depend on the methods, structures, and patterns that already exist in nature (Krebs & Bach, 2018). It is vital to understand that permaculture does not necessarily follow a specific set of practices. Some permaculture designers have developed their own techniques and concepts, but the core principles and values remain the same. A common trait, however, in all of these practices and techniques are the twelve major principles of permaculture. These include 1) Observe and Interact, 2) Catch and Store Energy, 3) Obtain a Yield, 4) Apply Self-Regulation and Accept Feedback, 5) Use and Value Renewable Resources and Services, 6) Produce No Waste, 7) Design from Patterns to Details, 8_ Integrate Rather Than Segregate, 9) Use Small and Slow Solutions, 10) Use and Value Diversity, 11) Use Edges and Value the Marginal, and 12) Creatively Use and Respond to Change (Veteto & Lockyer, 2008). Permaculture's founders, Bill Mollison and David Holmgren, shared concerns about the threats of excessive resource consumption, energy scarcity, and resource-intensive agricultural systems. They pulled on numerous sources and incorporated them with the ideas of our ever-advancing and adapting pre-industrial societies, developing an ecosystem theory and designs that were most applicable for the current environment using these 12 core principles. These principles offer a set of frameworks for people to design nature-friendly, sustainable land use and communities that stays within the ecological boundaries of land use, species, and the exchange of energy within them (Holmgren, 2020). Ecological boundaries are zones, in this case farms, in which a system of interaction between various entities such as soil, organisms living in the soil along with a diverse group of plants exchange energy amongst themselves to create a sustainable ecosystem.

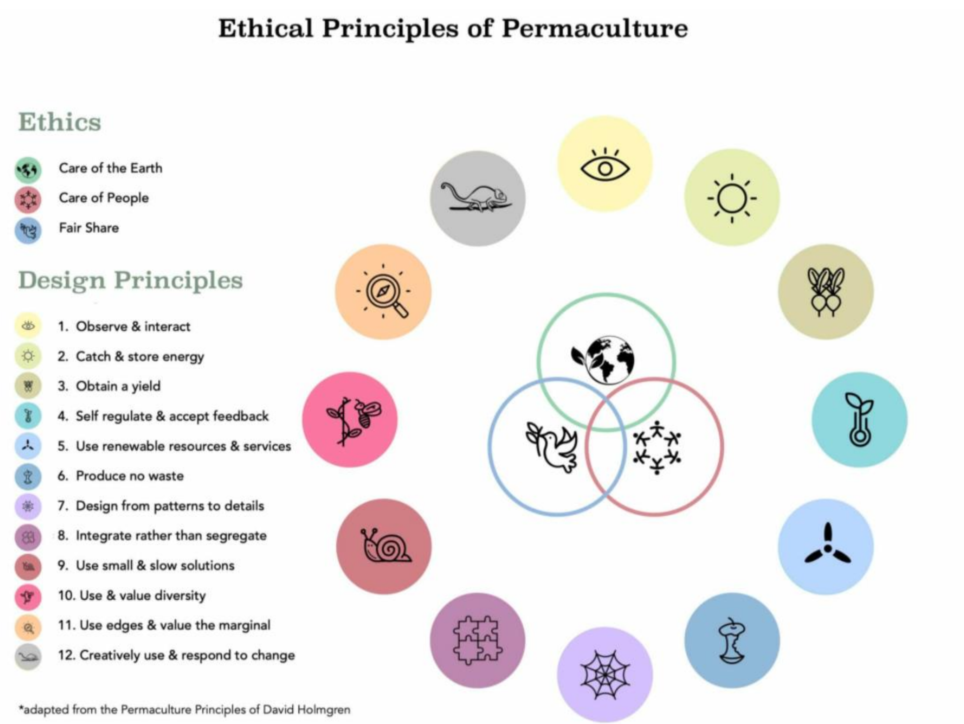

Figure 2. Principles of permaculture (Holmgren, 2020)

Permaculture Principle 1: Observe and Interact

All living beings have an innate nature of surviving and thriving by constantly observing and interacting with nature. Children observe and learn from their parents and families to become competent adults and adapt to the environment and culture they are born into. In the modern world, however, Bill Mollison points out that formal education frames a child's mindset and subsequently their life choices to a certain degree. In doing so, they are separated from the innate capacity of interacting and learning to look out for themselves.

Even though this principle addresses personal behavior, it also shifts our paradigm towards our potential and capability to design responses to emerging challenges and incorporate that into our designs of systems to facilitate learning by all living beings, including animals and plants. It encourages effective use and understanding of the natural patterns and human capabilities and discourages dependence on non-renewable energy.

Permaculture Principle 2: Catch and Store Energy

Earth is an abundant source of resources such as water, land, air, fossil fuels, and minerals which are a result of enormous storage and harvesting created by natural cycles over billions of years. An increase in population, settlement, and demand has resulted in over-harvesting that now is showing up in the form of pollution, fossil fuels decline, and climate change. Regardless of the forms in which the impacts are showing, the consumption of energy and natural resources is so reckless that if we do not stop, we might not have enough resources left for future generations.

Thus, this principle highlights the need as well as an opportunity to take advantage of the surplus resource and energy we have in the forms of water, sun, food, and wind when they are available and create a system that will sustain and support us in times of scarcity. Later in this paper, I give examples of swales and drip irrigation that will illustrate how this principle can be incorporated into permaculture designs.

Permaculture Principle 3: Obtain A Yield

Bill Morrison states, “you can’t work on an empty stomach” to describe the meaning of this principle (Holmgren, 2002, p. 13). In the above paragraph, we talked about the abundant resource on Earth and the need to make use of existing wealth. In this principle, however, we emphasize the need to have an immediate yield to feed ourselves in the current time because there is no point in planting a forest for the future if we can hardly survive today.

To generate some benefit and obtain productivity from an employee or staff member, you need to convince them of an immediate reward, such as a salary or information. Likewise, a yield or profit is a form of reward that motivates people to maintain the environment that helped generate the yield. This whole system can be viewed as a positive feedback loop. Obtaining a yield encourages and ensures success and growth that amplifies productivity, positive impact, and solutions.

Permaculture Principle 4: Apply Self-Regulation and Accept Feedback

This principle targets the self-regulation and reliance of a system and encourages practitioners to foster it by making each element in the system energy efficient. To design self-regulating systems, having a good understanding of how negative and positive feedbacks work in nature is important. The concept of feedbacks was introduced through electric engineering. Positive feedbacks are when there is an amplification of an effect by its influence on the process that results in an accelerated reaction. Likewise, negative feedbacks are the counteraction of an effect that reduces the output. Establishing a culture that is more aware of the feedback signals to prevent people from overexploiting resources is a challenge. It is also crucial to realize that there might be downfalls. The goal of permaculture is not to have zero hazards. We need more acceptance of these natural feedbacks, and we require corrective actions.

The Gaia hypothesis coined by James Lovelock defines our planet as a self-regulatory organism governed by positive and negative feedback loops. This concept has both negative and positive impacts on how we perceive the functionality of Earth. Environmentalists see this as a hope to restore resources and energy, while climate skeptics use this idea to argue that Earth innately has the potential to recycle or regenerate energy. Climate skeptics believe Earth has abundant and unlimited resources and is is almost impossible to overexploit these resources. They use this idea as an excuse to avoid discussion of whether humans have gone beyond the threshold of the Earth's capacity and overexploited natural resources. An understanding of both negative and positive feedback within a system is important to design permaculture systems.

Permaculture Principle 5: Use and Value Renewable Resources and Services

Permaculture designs highlight and make the best use of renewable energy and resources that are easily accessible to us. Renewable resources are those that we gain from plants, animals, water, and land - every natural component that can regenerate itself. Rainwater harvesting in our gardens or collecting rainwater through our roofs is an example of renewable resource use.

Permaculture focuses on and encourages harmonious interaction between humans and nature. This principle encourages us to use renewable energy in a way where we are not overconsuming resources. When we use a forest or a tree for wood, we are using renewable energy but at the same time, we are killing the trees. However, if we use this forest or tree for shade and shelter, we are gaining the benefits without consuming or harming it. This does not mean we do not consume resources at all; instead, permaculture design should make use of non-consumptive services to reduce consumption. It encourages the creation of systems and a culture that support responsible consumptive demands on resources. This is a simple understanding of redesigning natural systems using permaculture that encourages people to value and use renewable energy efficiently.

Permaculture Principle 6: Produce No Waste

This permaculture principle brings back traditional values of frugality from our older generations, i.e. valuing the resources we have right now and making use of materials we have at hand. Permaculture views waste as both a challenge and an opportunity for innovation. Creating designs that recycle and redevelop the waste that we generate in our daily lives could result in large efficiency gains that could be beneficial to our community and environment.

An example of this would be the use of greywater that runs off during heavy rainfall and collecting it in containers for drip irrigation, which we will talk about in more detail later. The primary focus should be on reducing waste that we produce in our households or our workplace. Permaculture also highlights some opportunities that can be created from the waste we generate. For instance, if we recycle our old clothes, someone else might obtain a yield from the waste of others. We can creatively reuse waste and make a sustainable system or pattern of living without burdening our planet.

Permaculture Principle 7: Design from Patterns to Details

Science and modern thinking tend to highlight the importance of understanding every little detail in the world. To grasp knowledge of something, we often find ourselves pulling things apart to see what makes them work. While that helps to get clarity on matters, it often tends to scramble our basic common sense or intuition to design patterns and systems that complement each other without having to integrate any complex ideas.

Permaculture emphasizes the importance of reading patterns. In other words, zooming out to see the world within a boundary, its inputs, and outputs of the system. Doing this allows us to see the world on a bigger scale and understand the details of the elements in the system. We can then use this pattern to design systems and use one pattern for another system as well. The skill of recognizing patterns can be the outcome of the first principle 1, i.e., observe and interact.

Permaculture Principle 8: Integrate Rather than Segregate

The notion of 'integrate rather than segregate' draws together elements of a system in a self-regulating design where each element interacts with others and benefits from their relationships. Our entire planet functions because of the interconnections between the organisms that make up ecosystems. Permaculture principles highlight these relationships, acknowledges how complex they are, and underlines the fact that relationships can sometimes destroy a system. The relationships vary; some might be predatory and competitive while others might be cooperative and symbiotic. It depends on the ability of the permaculture designer to identify these relationships and create integrated systems that depend on their characteristics. Permaculture, however, stresses constructing a mutually beneficial relationships amongst the system's elements.

Permaculture Principle 8: Use small and slow solutions

Every time we grow food or take care of our health, we are making efficient use of this principle. This is a self-reliant nature that we build in ourselves. We are creating a system that is designed in a way that functions at the smallest scale, which is practical and efficient. Whenever we buy locally or we contribute to environmental issues as an individual, we are applying this principle.

There are several examples of downfalls of fast-paced processes and systems that will help us understand this principle. When we use soluble synthetic fertilizers for crops, their response is fast paced but often short lived. Using natural fertilizers such as compost creates a more sustainable and balanced environment for the plants to thrive.

Permaculture Principle 9: Use and value diversity

Diversity in nature is both dynamic and complex. It can be favorable on the one hand and at times contradictory. Permaculture encourages people to see diversity and its value as a result of both balance and tension within the earth system. We perceive it as a possibility as well as a source of power and productivity in nature. Polyculture is one example of using diversity which has been widely recognized; however, it is not the only example available. In polyculture, different species of plants are grown either through crop rotation or side by side in a way that species complement each other (Neglia, 2021). Polyculture is one of the most important applications of this principle and allows plants to be self-reliant by creating a system where they are provide a wide range of goods and services to self-maintain and sustain each other. Unlike agriculture monoculture, polyculture reduces vulnerability to pests and market fluctuations.

Diversity by no means is limited to plants. It also extends to humans and our communities, which include people of diverse cultural backgrounds, experiences, and knowledge. This diversity amongst human beings is as important as the conservation of biodiversity. Therefore, the implementation of this principle is important to provide insurance against the challenges we face in nature, as well as an opportunity to creatively solving those challenges.

Permaculture Principle 10: Use Edges and Value the Marginal

This principle draws focuses on the values and contributions of edges. Edges are seen as marginalized aspects of life and are oftentimes overlooked or do not receive as much attention; however, edges play a significant role in earth's cycles. For instance, for every terrestrial ecosystem, soil acts as an interface between the biosphere, atmosphere, and the non-living earth (hydrosphere and lithosphere). The goal of permaculture design is not only to recognize and conserve edges, but to optimize their productivity to their utmost potential. In aquaculture, for example, the edges of a forest and pond can increase the productivity of both. To gain substantial results, we should see edges as an opportunity for productivity rather than a problem.

Permaculture Principle 11: Creatively Use and Respond to Change

Permaculture is about resilience within human beings and natural systems. It is also the ability of all living beings to adapt to the changing environment. This principle has two important threads: making use of the change in the world productively, and cooperatively responding or adapting to changes in innovative ways. Permaculture encourages adaptation to changes with flexibility rather than armored rigidity. We need to focus on designing and developing systems to cope with failing systems rather than putting our energy into demolishing or patching up existing problems.

From a designer's perspective, the first six principles (Figure 2), give a bottom-up perspective on our values, elements, and individuals, while the last six principles use a top-down perspective that focuses on patterns and interactions that come through co-evolution (Holmgren, 2002). These principles also interact and overlap with each other. In the design process of any environmental system, permaculture designers have noted that it is important to not just focus on one or two principles but to look at the system with a more holistic view and integrate the whole set of principles with one another, which helps create a balance within the system (Krebs & Bach, 2018).

Now that we have grasped the basic concept and principles of permaculture, we move on to understanding the benefits they can provide in an urban setting, specifically how they can be used to design urban farms and gardens – known popularly as ***urban permaculture***. Urban permaculture is the application of the principles we have discussed in an urban setting to produce results that are successful and adaptable. Urban permaculture is a movement that was initially started by city dwellers who aimed to lessen their environmental footprint by building an understanding of food systems and regain control over their consumption and production in urban and suburban environments (Giustra, 2020). Urban permaculture is a relatively new term, but many of the underlying principles have been in practice for hundreds or thousands of years, for example in the form of backyard and kitchen gardening. However, the objective and goals of the current movement are much more than simply gardening at home. Urban permaculture aims to transform cities, livelihoods, and the very ethics of a community by making the environment more regenerative and encouraging residents to limit waste, and helping them understand the natural patterns that create a continuous cycle, using everything to its fullest potential (Popović & Miljković, 2013). For instance, building a food forest, reclaiming graywater systems, using solar and wind power to minimize consumption of fueled energy are all part of urban permaculture. Urban permaculture aims to create a way of living that utilizes natural energy, minimizes waste, and increases efficiency.

As mentioned earlier, the permaculture network is evidence of the popularity and recognition it has been gaining worldwide. The World Permaculture Network has recorded and published an extensive database that helps connect people around the globe around permaculture ideas, practices, and projects they are involved in (Nierenberg, 2015). As of 2015, the site featured 1957 permaculture projects around the world (Nierenberg, 2015). Additionally, the benefits of permaculture have been highly recognized in the United States, and permaculture design courses for anyone who wants to gain deeper knowledge on the permaculture practices have seen increased enrollment in recent years. According to the director of the National Permaculture Institute, Scott Pittman, approximately 100,000 to 150,000 students have completed certification courses on permaculture around the world, of which 50,000 are from the US (Nierenberg, 2015). Confirming those statistics, Appleseed Permaculture reported that over 100,000 people are certified in permaculture practices in over 140 countries, with 4,000 ongoing projects on the ground (Nierenberg, 2015). Additionally, the use of permaculture has been instrumental in combatting food insecurity, inappropriate land use, water scarcity , and other issues that farmers face.

FARMING AND FOOD SECURITY IN WORCESTER

Farms in Worcester

In this section, I will be giving an overview of the farms, their total coverage, and prominent crops grown in Massachusetts to help readers understand the importance of urban farms in the state.

Overall, Massachusetts has approximately 7,241 farms, with 491,653 acres of farmland that generate a revenue of $475,184,000 from agricultural products (USDA, 2017). Approximately 25,920 individuals are employed in the agriculture sector and the average farm of about 68 acres produces about $65,624 worth of agricultural products (USDA, 2017). Most crops are grown in greenhouses and nurseries, which make up one-third of the state's total production (Inglis, 2017). The most commonly gown vegetables are tomatoes, spinach, lettuce, broccoli, cauliflowers, and herbs. Apples, cranberries, and sweet corn are also some common fruits and vegetables produced in Massachusetts, and generate 35% of the state’s agricultural revenue (Mensoian et al., 2006). Cranberries are one of the most popular crop products in the state. Approximately, 25% of the nation’s cranberries are grown in Massachusetts (Mensoian et al., 2006). Livestock products, specificially dairy products generates 12% of Massachusetts agricultural income (Mensoian et al., 2006). Cattles, aquaculture, turkey, and chicken eggs are also important livestock products in the state (Mensoian et al., 2006). Most Massachusetts farms are small (about 1 to 9 acres) (USDA, 2017). The Massachusetts Department of Agriculture Resources reported that 94.2% of farms in

Massachusetts are small farms and 79.7% of farms are individually owned, mostly by a single family (USDA, 2017).

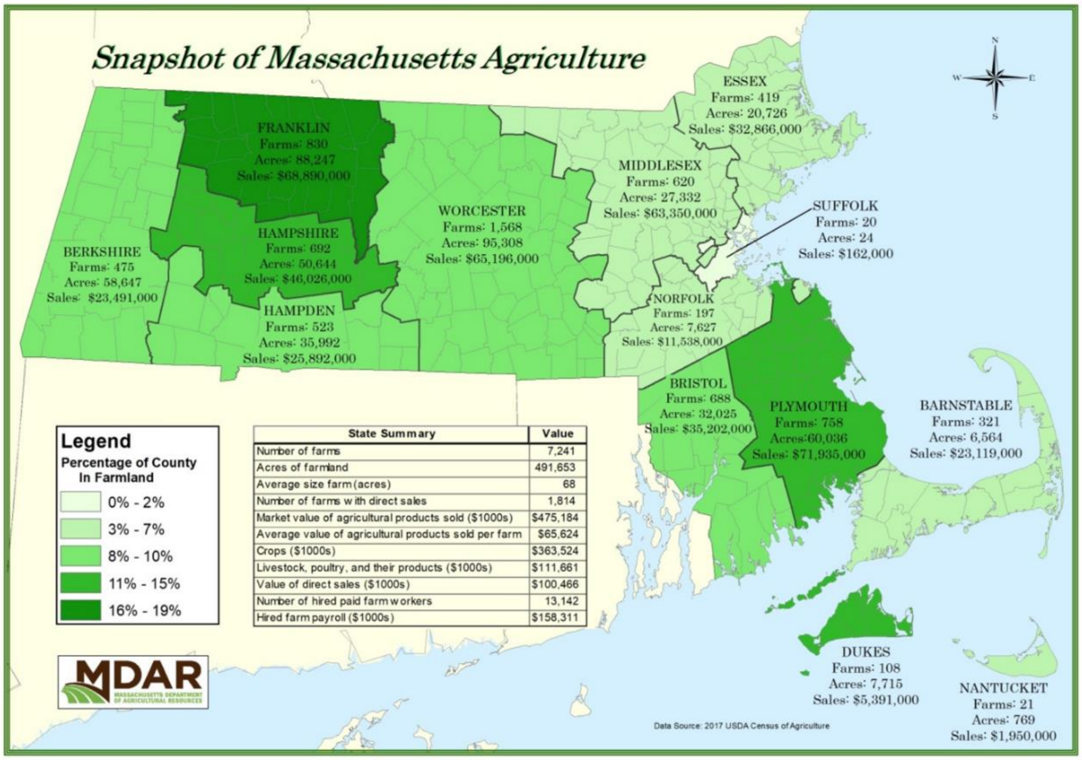

Figure 3. Agriculture in Massachusetts by county (USDA, 2017)

According to the 2017 Census of Agriculture, reported by USDA, Worcester County has approximately 1,568 farms that occupy 95,308 acres and produce $65 million in sales (Figure 3). Worcester County has the highest number of farms in Massachusetts. As of 2017, 35% of the farms in Worcester County were between 1 and 9 acres and 33% were between 10 and 49 acres (USDA, 2017). However, only 2% of farms have adopted organic farming techniques. Since 2012, the net income for farmers has increased by 42%, to a total of $8,143,000. This increase is due in part to the efforts of the local agriculture commissions and food policy councils. Furthermore, local non-profit organizations including food justice initiatives have encouraged communities to invest in community farms and have dedicated themselves to building sustainable, healthy, and just communities in Worcester.

Food insecurity in Worcester

Food insecurity is a complex issue and a global challenge that is prevalent in North America. About 10.5% (13.7 million) US households were food insecure in 2019 (USDA, 2020). The Food and Agricultural Organization of the United Nations (FAO) defines food insecurity as a lack of consistent and secure access to nutritious and safe food that is required to lead an active and healthy life (Napoli et al., 2010). While hunger refers to physical discomfort due to lack of food, food insecurity is most often attributed to a lack of financial resources to afford food at the household level. In 2018, the USDA reported that 1 in 9 Americans were food insecure, equivalent to over 37 million Americans, including over 11 million children (Coleman-Jensen et al., 2018). According to Worcester Food Bank, 1 in 11 residents of Worcester County, i.e., approximately 80,000 people including 21,430 children, faced food insecurity in 2019 (MacDougall, 2019).

Studies show that residents of Worcester face health risks based on the amount of food they eat and quality of their diet (Chen et al., 2015). According to a report published by MassCHIP based on recorded health patterns from 2001 to 2010, the obesity rate in Worcester has been consistently higher than the average rate for Massachusetts (Figure 4). One of the major reasons for obesity is unhealthy eating habits (CDC, 2021). Limited access to fresh food means many people depend on cheap fast foods, which leads to several health issues, one of them being obesity. Adults living in Worcester also have higher rates of diabetes, hypertension, and fair to poor health as compared to the rest of Massachusetts (Figure 5) (Chen et al., 2015). While the causes for these disparities cannot be completely attributed to food insecurity, it certainly demonstrates the need for attention to food systems in Worcester.

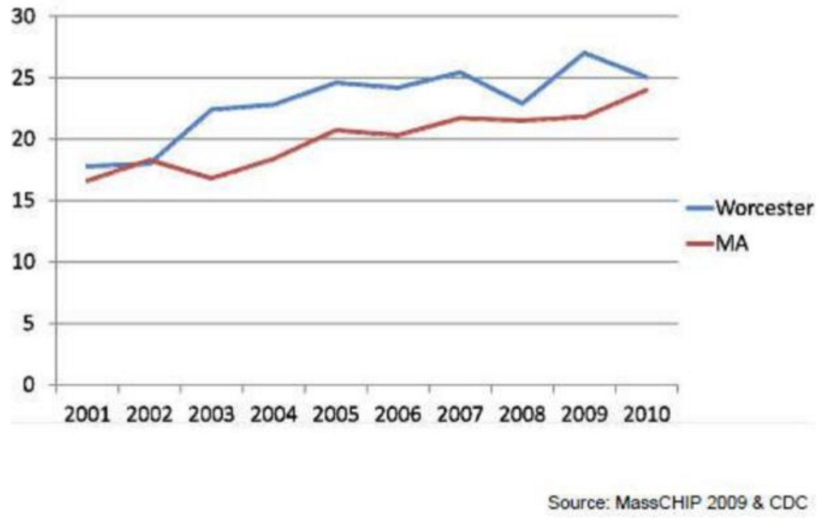

Figure 4. Obesity among adults in Worcester compared with Massachusetts (Chen et al., 2015)..

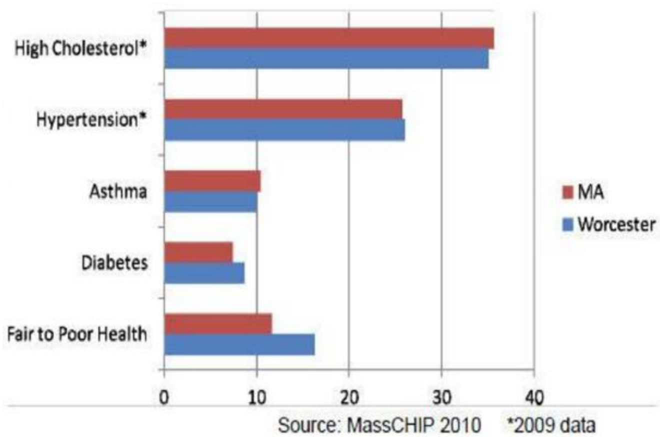

Figure 5. Chronic disease among adults in Worcester compared with Massachusetts (Chen et al., 2015).

Climate change impacts on agriculture

In this section, I will be talking about the challenges that climate change brings in terms of extreme weather patterns and fluctuating precipitation that stress water resources for farms in Worcester County.

Agricultural production in Massachusetts is already at risk of exposure to several hazards associated with climate change (Harriman & Cooley, 2019). Climate experts from Harvard University conducted a survey of farmers in Massachusetts in 2019 and found that a large number of farmers are already dealing with impacts of climate change on their farms, including fluctuating temperatures and precipitation (Harriman & Cooley, 2019). Research shows that the impacts of climate change will damage natural resources, the environment, and the economy, including small family-owned farms (79.7% of farms are owned by families (USDA, 2017). Climate change will increase the frequency of extreme weather events, such as prolonged droughts and high rainfall resulting in floods, as well as more variability in seasonal and daily temperatures (Harriman & Cooley, 2019). The impacts of climate change on agriculture in the Northeastern United States have already been observed (Harriman & Cooley, 2019). The causes of weather-related crop losses in 2013 to 2016 are summarized in the report published by Wolfe et al. (2018).

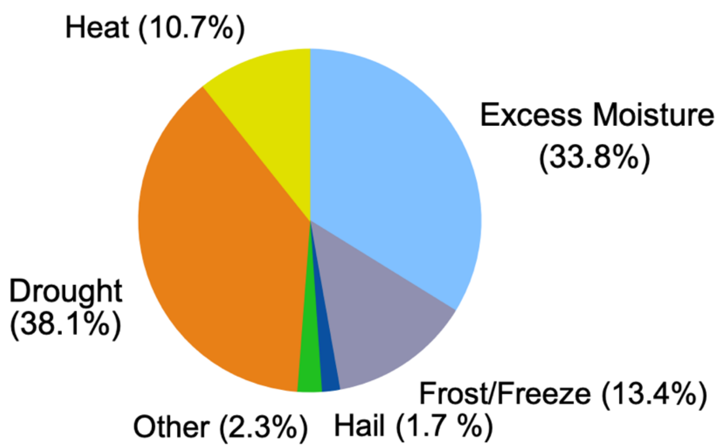

Figure 6. Causes of weather-related crop loss in the northeastern United States in 2013-2016 (Wolfe et al., 2018).

The climate in the Northeastern United States is humid, with rainfall spread throughout the year (Wolfe et al., 2018). Nevertheless, to fully meet each crop's water requirement and for farms to reach their maximum yield, irrigation is oftenrequired (Wolfe et al., 2018). The USDA’s Farm Service Agency reported that approximately 40% of major crop losses between the years 2013 and 2016 in the Northeast were caused by prolonged drought with year-to-year variability (Wolfe et al., 2018). Climate change projections for precipitation suggest that while the Northeast may suffer from a significant decline in rainfall, it is likely to maintain sufficient water supplies for agriculture. However, the drought that occurred in the summer of 2016, which resulted in record-low stream flows suggest otherwise. That event increased awareness about the increasing unpredictability of the weather patterns and brought attention to the need for better infrastructure, practices, and sustainable water conservation and management techniques for farmers . While many fruit and vegetable crops have some resilience, irrigation during prolonged summer droughts may become necessary, and very few farmers have the necessary equipment to meet their needs (Wolfe et al., 2018). Additionally, as compared to other regions in the US, farmers in the Northeast have little awareness or knowledge about irrigation technologies that use less water (Harriman & Cooley, 2019). Farmers are likely to be vulnerable to increased fluctuation in temperature and precipitation patterns and will face complex situations that require new water-conserving irrigation techniques soon.

Climate change vulnerabilities in Worcester

In 2019, the City of Worcester declared a climate emergency, stating that climate change threatens our natural environment. This declaration came after the Paris Agreement in April 2016, when world leaders from 175 countries recognized the threat of climate change in the IPCC report, along with many academic research articles and reports that projected a significant fluctuation in the weather patterns, specifically in precipitation and temperature (Ledoux, 2019). The City of Worcester recognized the efforts of residents of Worcester and academic institutions, and focused on food security as one of the areas of interests and impact that will be integral to the mobilization effort (Kleinfelder, 2019). In 2019, as a part of the Municipal Vulnerability Preparedness (MVP) Plan, community stakeholders identified three major climate change hazards: flooding from extreme precipitation; ice, and snowstorms due to extreme cold; and extreme heat coupled with drought (Kleinfelder, 2019).

The effects of climate change have been evident in the City of Worcester in recent years. There are several faces and layers of climate change; one that is apparent in Worcester is conflicting and fluctuating weather events such as intense precipitation, prolonged heat waves causing droughts and extreme cold weather intensifying snowstorms. Worcester was designated as America's 2nd Snowiest City during the 2012-2013 and 2014-1015 winters (Kleinfelder, 2019). Similarly, prolonged heatwaves have also been more frequent in the city. Over the last ten years, reports show that climate change has led to extreme heatwaves during summer months; in 2009, Massachusetts declared a severe drought, and in 2016, Worcester experienced a Stage 3 drought

(Annear, 2016). The same year, a heavy precipitation event caused severe flooding, impacting the waterways and revealing vulnerabilities in Worcester's stormwater system.

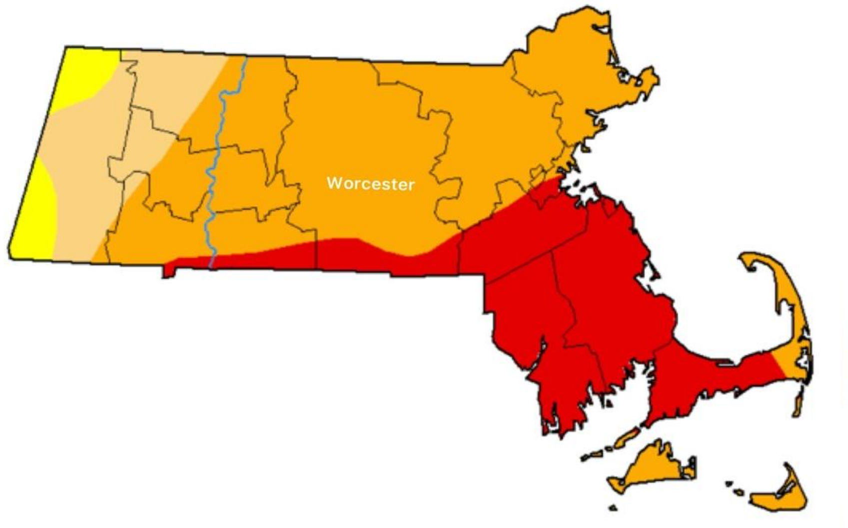

Figure 7. Drought intensity in 2019 in Massachusetts according to the North American Drought Monitor (NADM); white = none; yellow = abnormally dry; cream = moderately dry; orange = severe drought; red = extreme drought (Fuchs, 2019).

The North American Drought Monitor (NADM) website publishes maps of drought conditions in Canada, Mexico, and North America (Fuchs, 2019). Figure 7, a map developed by NADM, shows us the intensity of the drought in Massachusetts. The conditions range from none (no drought) to extreme drought conditions. 'Abnormally dry' zones (yellow on the map) experience impacts on crop growth, delayed planting, increased wildfire, early spring fire season, and declining surface water. In 'moderately dry' areas (cream color), the impacts of drough include increased use of irrigation; hay and grain yields lower than normal; increased risk of wildfire; stress on trees and landscapes; stress on fish populations; lake water levels below normal capacity; and voluntary water conservation requested. For 'severe drought' (orange) zones, water quality is poor, groundwater is declining, and irrigation ponds are dry; formal restrictions on the use of water outdoors re implemented; trees are brittle and susceptible to insects; crops are impacted in both yield and fruit size. Lastly, 'extreme drought' zones (in red) are more susceptible to extremely reduced to complete cessation of stream flow; river temperatures are warm; wells run dry; people start digging more and deeper wells; water recreation is modified; and bulk water haulers are seen to increase in use, since the efficacy of irrigation from surface water sources are limited; crop loss is widespread [cite source]. Observing these levels across the state of Massachusetts in 2019, it is clear that water scarcity is already a major issue that needs to be directed with change in practice.

XERISCAPING

The term “xeriscape” was coined in the 1980s in the city of Denver, Colorado. Xeriscaping is a compound word comprised of the word “xeros”, which means “arid” in Greek and the word “landscape”. It is a landscape designing method that has ecologic, economic, and aesthetic benefits for a community. The basic strategies and approaches proposed in xeriscaping design focus on drawing elements of nature together in a more integrated system. These integrated systems are designed in such a way that each component is practical and energy efficient by nature or is designed that way. The farms and gardens using xeriscaping strategies are self-reliant and water-efficient through the integration of drought-resistant plants that improve soil quality and reduce chemical and pesticide use to prevent contamination of groundwater (Çetin et al., 2018). Some of the economic advantages of this design are reducing labor costs, requiring less time for maintenance, saving effort and energy, resulting in lower electricity and water bills (Çetin et al., 2018).

Xeriscaping design advocates natural water-saving landscapes in farms instead of traditional landscape concepts or the ones that emphasize “techno-driven” methods such as the use of renewable energy (solar or hydro) that are self-reliant and energy-efficient (Holmgren, 2020). Xeriscaping is one of those practices that takes a holistic approach in assessment, planning, designing, and picks out suitable and appropriate plant species that are drought resistant. It uses water-efficient irrigation techniques to make farmlands more sustainable and climate-resilient. Many scholars have found that the approaches taken in xeriscaping capture a large amount of CO_2 with lower irrigation requirements than other sequestration approaches (Çetin et al., 2018). Eliminating the need for yard equipment that uses fossil fuels helps reduce the carbon footprint and helps promote natural habitat for the crops and soil (Çetin et al., 2018). Xeriscaping any garden/farm space could reduce the need for pesticides, increase soil quality, and subsequently benefit healthy eating in the community. The use of cover crops and mulches to help plants maintain their own growth rates without the help of pesticides is beneficial. Xeriscaping helps conserve water, improves soil quality, and promotes eco-friendly, naturally sustaining, easily adaptable crops that save energy and time while increasing the productivity of a farm (Wilkinson, 2015).

Xeriscaping methods incorporate all 12 of the permaculture principles discussed earlier. We will discuss the implementation of those principles into practical use in the following sections.

Use of drought resistant perennial crops

Permaculture designs strongly focus on perennial plants and emphasize their benefits over using annual plants in agriculture. Annual plants are grown in 70% of the world's cropland area, leading to loss of fertile land, depleted groundwater, an increase in pests, and erosion of biodiversity (Seaman, 2011). To revive and restore agriculture, permaculture introduces perennial plants as a sustainable and productive transition to the practice while meeting the needs of farmers. It is crucial to utilize perennial plants when we consider permaculture, as these plants help construct permanent systems. The seventh permaculture design principle – small-scale intensive system – explicitly states the importance of perennial plants while designing small-scale gardens and farms.

Unlike annual plants that grow only one season, perennials can last through the seasons after a single harvest. Perennial species regrow and reproduce seeds, grains, biomass, and fruits and do not require as much effort as an annual plant. They can be harvested multiple times, sometimes more than 10 years (FAO, 2021). Perennial plants have a natural tendency to be more consistent and abundant, which results in long-lasting, affordable food, fiber, and fuel. Planting perennials maintains soil biota, structure, and quality because they have deep roots that support stability and nutrient enrichment over time. Additionally, perennial plants do not require fertilizers and energy inputs which adheres to the ninth principle of permaculture: use and value renewable resources and services. Moreover, perennial plants have a high water-saving efficiency that improves climate resiliency. Agricultural systems with annual plants as their predominant crops are more susceptible to water loss due to soil evaporation and surface runoff. Studies from the Midwestern United States show results and insights into the water use efficiency, along with the productivity of perennial plants (Hamilton et al., 2015). Scientists have found that perennial plants have enhanced soil hydrological function, higher infiltration rates, and relatively lower runoff rates. In an experiment comparing switchgrass (a perennial) with maize, the tradeoff between carbon and water in the experiment provided a strong indicator of productivity per use of water (Basche & Edelson, 2017).

In Worcester, where we have small-scale farms, the use of perennial plants could increase the productivity of these farms at the lowest cost, effort, and adaptability. Magenta plants, for instance, are native to North America and blooms throughout summer; they can survive the water scarcity during the heat of summer. Plants like coneflowers and daylilies are tough plants that do not require much water or fertilizer and are pest resistant that is commonly found around Worcester. Likewise, sorrel (*Rumex acetosa*) is a vegetable that is often overlooked in gardens but is a multifunctional perennial species (Toensmeier, 2014). A cultivar of sorrel known as "Profusion" has deep roots and contains healthy nutritients like calcium, phosphorus, and potassium in its leaves. Sorrel grows in partially shaded areas and require little water to survive, which is perfect during seasonal droughts (Toensmeier, 2014). Sunchokes, also known as Jerusalem artichokes, is another perennial vegetable that can be grown in cold weather. Their tubers store their energy in the form of starch during winter. Sea kale broccolis, Turkish rocket broccolis, purple asparagus, Chinese artichoke, and rhubarb are other perennial vegetables that are perfect for Worcester weather (Toensmeier, 2014). Perennial plants will also help to retain and build the soil and conserve the available land we have for community gardens around Worcester.

Swales

Swales are a prime example of several permaculture principles, including catching and storing energy, obtaining a yield, applying self-regulation and accepting feedback, use and valuing renewable resources and services, and using edges and valuing the marginal. It encourages the recycling of natural energy by capturing, storing, and creating a system where the resource reuses itself, self-sustaining the entire cycle on site. Swales can be referred to as "engineered vegetated ditches" that help in the infiltration of water, storage, and low-cost drainage for urban farms. The EPA recognizes swales' potential to reduce the environmental footprint of food production while meeting the needs of the crops and the farm to manage water-related challenges such as drought(Borst et al., 2012).

Figure 8. Demonstration of a swale design on a small garden plot (Plant Justice, 2009)

Swales are suitable for low-lying areas, as water flows downhill. Designing and forming swales requires a thorough site assessment to identify the best spots and dig trenches along the contour of the farm (Nolasco, 2013). These trenches capture water after heavy rainfall and hold the water for some time before it percolates into the soil. Ideally, swales are dug at a slightly higher elevation than raised garden beds or trees as these trenches help enhance the soil moisture and recharge groundwater. It also helps to store water temporarily on site.

Swales help slow down the flow of the water and hold it long enough for the perennial plants to absorb the nutrients and benefit from the soil moisture. The holistic design of the urban permaculture farm means its components can complement each other if they're designed and planned out carefully. As permaculture principles 7 and 8 state, (design from patterns to details and integrate rather than segregate) integrating perennial plants alongside swales will help urban farms gain productivity.

Drip Irrigation

Drip irrigation is a water-efficient irrigation technique which is also known as micro or trickle irrigation. Drip irrigation is characterized by slow and accurate flow of water in farms. This irrigation system can be applied to farms of any size and can also be a cost-effective way of irrigation. Drip systems are comprised of tubes connected to cisterns or greywater diversion(Nolasco, 2013). Irrigation efficiencies for this method are 88-90% depending on the weather conditions, which is higher than more conventional, open systems known as flood irrigation (Nolasco, 2013). Additionally, drip irrigation is one of the most efficient ways to water crops using wastewater. Crops can benefit from the use of wastewater if used properly. Recycling or reusing wastewater is particularly valuable in places that have water scarcity. However, municipal wastewater can be heavy with toxic chemicals or microorganisms that pose potential harm to human health, so it is important that only domestic greywater or water that has been properly treated be used in drip irrigation systems. Furthermore, drip irrigation systems should be attached to a suitable filtering apparatus that will clear debris that could potentially clog or contaminate the system (Nolasco, 2013).

Figure 9. Drip irrigation system inside a high tunnel (top) and multiple watering hoses attached to a raised bed (bottom) (Jacobson, 2018)

Hügelkultur

Hügelkultur technique has been used for centuries in the form of "grandma's ways of reusing old debris", but it was only in 1962 that gardener Herrman Andrä recognized this practice as a permaculture method (Laffoon, 2016). The term hügelkultur is derived from German for "mound culture". These mound beds are made up of decomposing wood to imitate the nutrient cycle that occurs in forests. The rotting wood, consisting of trimmed branches or debris of various diameters, are typically mounded and covered with a layer or two of green manure, compost, and a layer of topsoil. This method increases water holding capacity and thereby provides crops with moisture during drought seasons. Hügelkulture beds are designed in such a way that the decaying woods at the center of the structure acts as a water reservoir for the plants to absorb and helps encourage a low maintenance composting system (Laffoon, 2016). It also improves drainage properties as well as the bed structures on which crops are planted.

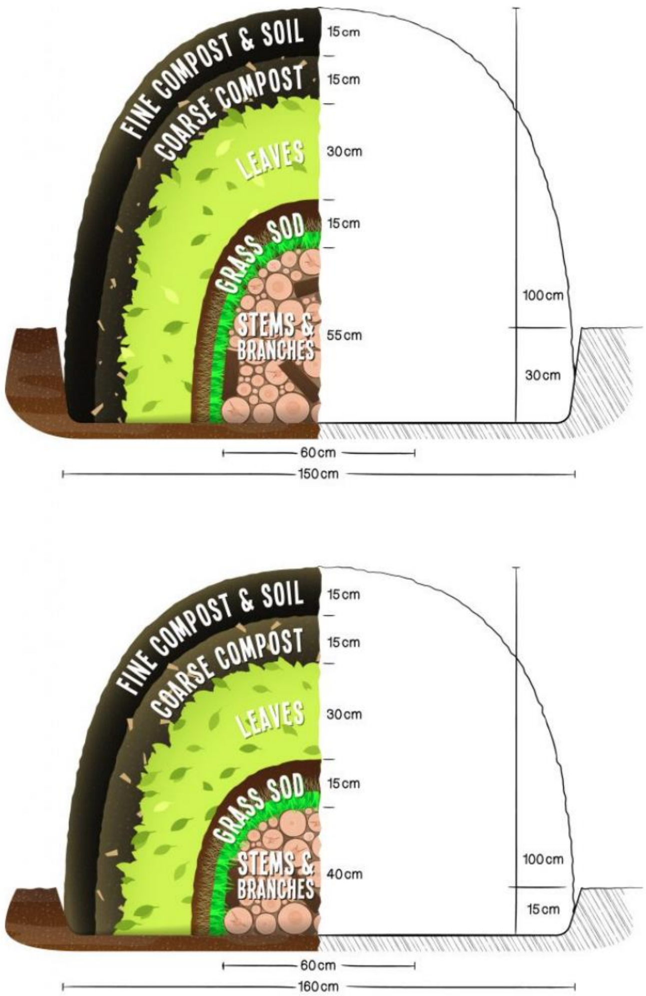

Figure 10. Representation of Hügelkultur mound construction (Beba & Andra, 1985)

A study of the water storage properties of hügelkultur beds in Kentucky assessed the performance of hügels over time and compared them to non-hügled land (Laffoon, 2016). After measuring the moisture content of the soil for three months, the researchers concluded that the hügelkultur system could hold more water, since the water concentration levels in the hügelkultur beds were higher than the control beds. The hügels constructed with wood debris contained an average of 59% water while the control beds contained 33% water. The authors concluded that although this method required a large amount of organic material (logs, soil, and straw) at the beginning, it lasted longer and could be used as a no-till agricultural system (Laffoon, 2016) that would conserve water in the context of climate change.

Figure 11. Step-by-step process in the Hügelkultur Garden Demonstration Project (Griesemer, 2016)

RECOMMENDATIONS

This section will provide some key recommendations to address issues and challenges within permaculture practices, knowledge, and awareness. These recommendations are targeted towards permaculture practitioners, institutions, local and municipal government, the general public, and non-profits like the Regional Environmental Council that promote urban agriculture.

Although the permaculture concept, its practices, and techniques are well established, there is scarce empirical scientific knowledge and peer-reviewed papers on permaculture systems. Published scientific knowledge is very little, whereas publications on permaculture are more popular from independent authors who are often self-trained. For instance, organic agriculture has been studied through a scientific approach for a long time, thus its standards in terms of practicality and technique are well recognized. Organic agriculture has gained respect from both the scientific community as well as political decision-makers for years. Permaculture, however, has not received the same recognition. Therefore, for the permaculture movement to gain similar respect and trust, further scientific research to generate reliable knowledge and information are critical.

By now it should be clear that permaculture is a multi-faceted framework that has several layers and areas of emphasis. It is important to understand all of those principles and their interconnectedness. Based on understanding those principles, it is important to learn to implement them in practice. The productivity of permaculture should be based on well-researched and robust experimental data rather than anecdotal evidence. This will allow decision-makers to get a concrete idea of the measures that permaculture encourages. There should be peer-reviewed scientific evidence that these approaches enhance soil management, water conservation, and other aspects of food production. Empirical research should include consideration of the economic viability as well as the ecological footprint of permaculture. In addition, proponents of permaculture should avoid unsubstantiated claims and develop accurate quantitative evidence to strengthen their advocacy. For instance, both short-term and long-term economic viability could be one of the major areas to investigate, by quantifying agricultural benefits in terms of total production, changes in soil fertility, and water use. These measurable outcomes would encourage farmers and communities to adopt these practices.

There are several permaculture design courses and resources online that help practitioners gain insight on the implementation of several permaculture practices. Numerous permaculture groups around the globe have created online communities where they share their ideas and successes. Involving more people in those groups will help create a community that is benefits from knowledge sharing and a sense of community.

Additionally, while designing farms with the permaculture techniques that I introduced above, integrating those methods will create a system in which components co-benefit and complement one another. For instance, as mentioned above, integrating perennial plants alongside these swales will help these farms gain increased productivity. As permaculture principle seven states, it is important to trust our instincts and read patterns while designing farms. Even though the above-mentioned permaculture techniques are targeted for Worcester gardens and farms, not all designs would produce the desired results. This could be due to topography, soil quality, or lack of adequate resources. However, the beauty of permaculture is that these designs are customizable according to farmers' and gardeners' needs and aspirations. Therefore, imagination and creativity are at the core of permaculture.

CONCLUSION

Climate change and global warming observed over the past several decades have been associated with change in the components of the hydrological cycle, including change in precipitation patterns, increasing evaporation and runoff. Water conservation, therefore, is imperative to maintain ecological balance. In Worcester, the impacts of climate change in the form of fluctuating weather events (such as intense precipitation, prolonged heat waves causing droughts and extreme cold weather intensifying snowstorms) threaten urban farms and agriculture and therefore future food security. Thus, communities require a simple yet sustainable approach to these challenges that people from any household can adopt on an individual level. Permaculture addresses the crucial relationships and interconnectedness between nature and human beings through a framework that can be adapted on a local scale. It can bring institutional and long-lasting solutions to protect our planet's future, which now seems in jeopardy due to climate-related risks. This paper focused on urban agriculture to address some useful permaculture practices and techniques such as the use of perennial plants, creating swales, drip irrigation, and hügelkultur. Communities and environmental organizations working on food security can help locals practice and adapt these techniques. In addressing permaculture principles and their framework, this paper encourages communities and individuals to reflect on their personal choices and perceive nature itself as a resource that can be recycled, reused, and regenerated efficiently.

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