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Research Paper

Urban heat islands as agricultural opportunities: An innovative approach

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HIGHLIGHTS

- The urban climate of Toronto is considerably warmer than it was a century ago.
- The warming is a result of urbanization and not global climate change.
- Growing degree days in Toronto have increased from 1000 to 1500.
- Crops can be grown in Toronto that would not survive in nearby rural areas.

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ABSTRACT

Many cities are experiencing an Urban Heat Island (UHI) effect and a substantial amount of research has focused on ameliorating those conditions. However, few studies have proposed taking advantage of them. This research investigated the potential for growing food crops in hot urban microclimates that would not grow successfully in the surrounding rural area.

Growing degree days (GDDs) and grapevine winter hardiness were used to simulate how the UHI might affect plant growth in Toronto, Canada. Modelled leaf temperature was used to analyze urban microclimate variability and implications for plant growth.

GDDs in Toronto have increased from an average around 1000 in the mid-1800's to an average around 1500 today, but have remained unchanged in the rural area outside the city. The urbanization of Toronto has caused longer, hotter growing seasons, and warmer winters. Given the appropriate microclimate combined with UHI effects Toronto could likely support the growth of warmer-climate crops that would not otherwise grow successfully in Ontario.

1. Introduction

More than half of the world's population lives in urban areas and it is expected that the percentage will to continue rise (World Health Organization, 2014). Heightened temperatures within urban areas compared to the surrounding rural areas, known as the urban heat island (UHI) effect, have been well-documented (Alcoforado & Matzarakis, 2010; Dimoudi, Kantzioura, Zoras, Pallas, & Kosmopoulos, 2013; Maloley, 2010; Voogt & Oke, 2003) and are experienced in cities around the world.

The reasons that urban areas are warmer than rural areas are well understood. These include: more solar radiation is absorbed due to tall buildings increasing surface area; more of the solar radiation is stored as sensible heat due to higher thermal admittance of hard surfaces; less terrestrial, or long-wave, radiation is lost due to restricted sky view factor; there is less evapotranspiration from soil, plants, and open water as these are replaced by hard surfaces; there is less wind at ground level meaning the heated air does not dissipate as quickly, and; there is anthropogenic heat exhausted from buildings, automobiles, and other sources (Oke, 1987).

As the variables above vary greatly from site to site so does the intensity of the UHI. Although air temperatures tend to remain relatively homogenous as wind mixes and moves the air, sunny sites that have large amounts of paving and very little vegetation often have much higher levels of both solar and terrestrial radiation (Brown, 2010; Oke, 1987).

The urban heat island can affect the growth cycle of plants when compared to their growth in rural areas (Jochner, Alves-

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eigenheer, & Patr, 2013; Mimet, Pellissier, Quénol, & Aguejdad, 2009). Urban agriculture, then, has different climatic opportunities and constraints compared to rural agriculture that need to be understood.

Much attention has been placed on mitigating the effects of the UHI; however, there has been very little work that attempts to take advantage of it. This study proposes the UHI be explored for its advantage. The longer and warmer growing season and the milder winters that are found in major urban centres could potentially provide enough climatic difference to grow foods that would not grow successfully in the rural areas surrounding the city.

This study analyzed the urban climate of Toronto, Ontario, and compared the findings to that of a nearby rural control – Elora, Ontario. Grapevines were used to test the effect of the urban climate on winter survival, date of budbreak, and time to maturation/harvest. Grapevines were chosen because of the extensive amount of available information on the climatic requirements. Such information is not readily available for other crops.

Toronto is a very culturally-diverse city, almost half of Toronto's population identifies themselves as having a native language other than English or French (Statistics Canada, 2011). With this cultural diversity comes a large demand for ethno-cultural foods, most of which are currently imported resulting in lower quality produce (Filson, Adekunle, & Sethuratnam, 2008). Many of the ethnic foods that are identified as being in demand in Toronto can be grown locally. Some, however, require a warmer climate or longer growing season than the southern Ontario climate can provide. Filson et al. (2008) identify an immediate need for information about growing the ethnic fruits and vegetables that are identified as being in high demand.

It is possible, then, that the UHI coupled with the right microclimate could allow for some of the demand for warmer-climate ethnic foods to be produced locally. This would reduce the travel-related fuel consumption, provide fresher produce to the consumers, and create a niche market for current or new farmers.

The heightened temperatures of the UHI are not evenly distributed throughout urban areas. Decreased Sky View Factor (SVF), which is the amount of sky that is visible from a given location, and increased proportion of impervious surfaces are both cited as being good indicators of UHI intensity (Chen et al., 2012; Oke, 1987; Stewart & Oke, 2012).

Urban conditions have been shown to have an effect on plant phenology, the recurring phases of plant life-cycle events (Jochner et al., 2013; Mimet et al., 2009). These studies have reported that urban conditions cause earlier onset of various phenological phases, primarily spring phases. Mimet et al. (2009) found that the phenological phases were more variable in urban areas than in rural areas, but urban trees consistently flowered before their rural counterparts. Both Jochner et al. (2013) and Mimet et al. (2009) reported that air temperature has the greatest effect on plant phenology; specifically that the reduced diurnal temperature range (daily max. – daily min. temp.) within urban areas is the main cause for the advanced spring phenological phases. This is supported by the fact that long warm nights have been found to induce accelerated flowering in food crops (Papadakis, 1975). Accelerated flowering in food crops, however, can have negative impacts such as low yields or tall, weak plants. Selecting crops that tolerate, or even prefer, warmer nights may prove to be an important step in choosing crops that could take advantage of the urban heat island.

During photosynthesis leaves open their stomata to allow CO_2 from the air to enter and O_2 from the leaf to exit, and in the process transpire water vapour. Transpiration helps regulate the temperature of leaves by evaporative cooling, higher transpiration rates occurring at higher temperatures (Flexas et al., 2012). When plants have adequate water supply they adjust transpiration rates as needed in an attempt to keep leaves within the optimum temperature range for photosynthesis (Burke & Upchurch, 1989). If there is an insufficient supply of water or temperatures exceed the cooling abilities of transpiration, stomata are closed to preserve water and photosynthesis is limited or stopped altogether (Flexas et al., 2012).

Plants adapted to different climates have different optimum leaf temperatures for photosynthesis (Dawson, 2005). Wheat has been found to have an optimum leaf temperature around 25 °C (Kobza & Edwards, 1987) whereas habanero pepper was found to have an optimum leaf temperature of 30–35 °C (Garruña-Hernández, Orellana, Larque-Saavedra, & Canto, 2014).

Using a leaf temperature equation (Oke, 1987) and a leaf temperature model by Dawson and Tu (2005) urban leaves with good access to sunlight will be, on average, warmer than their rural counterparts due to higher air temperatures, lower wind speeds (less convective cooling), more terrestrial radiation received from surrounding buildings and paved surfaces, and reduced radiative cooling caused by a lower SVF. Reduced solar radiation, caused by urban air pollution, will slightly reduce the temperature of a sunlit leaf; however, the models predict that the warming tendencies of urban areas will outweigh the reduced solar radiation. A leaf that is located in a shady location, such as to the north of a tall building, would receive little to no direct solar radiation and this would lead to significantly reduced average leaf temperatures.

Soil temperatures determine when agricultural seeds can be sown in the spring with typical minimums ranging from about 1.5 °C to 16 °C and optimums typically ranging from 24 °C to 35 °C (Kemble & Musgrove, 2006). Increased soil temperatures can accelerate seed germination and plant growth (Anderson & McNaughton, 1973; Bachmann, 2005). Urban soils are on average 0.5–3.0 °C warmer than rural soils with the greatest difference occurring at night (Klene, Nelson, & Hinkel, 2012; Tang et al., 2011; Ziska, Bunce, & Goins, 2004). Urban soil temperatures are more variable than rural soils, one study found soil temperatures in some urban sites to be as high as 8 °C warmer than the rural soil (Tang et al., 2011). Plastic 'mulches' are a common practice in market and organic farms to increase soil temperatures, among other benefits. Plastic mulches can increase soil temperature for warmer-climate crops in cooler climates, and they can maintain soil temperatures at acceptable ranges during the cooler shoulder seasons – effectively extending the growing period (Bachmann, 2005). Black plastic mulch can raise soil temperature by around 3 °C, a similar increase to urbanization (Orzolek & Lamont, n.d.).

Many perennial plants in temperate climates acclimate and deacclimate to below-freezing temperatures, being able to withstand colder temperatures in the middle of winter than at the beginning or end (Thomashow, 1999). Acclimation and deacclimation rates and initial and maximum cold hardiness temperatures are known for many grape varieties. This, paired with weather data, makes it possible to predict what temperature would cause damage to grapevine buds at a given time and when budbreak will occur in the spring (Ferguson, Tarara, Mills, Grove, & Keller, 2011; Ferguson, Moyer, Mills, Hoogenboom, & Keller, 2013).

Existing literature discusses the climatic effects of the urban heat island; however, it is unclear how these changes might influence what types of food crops could be grown in urban areas. There is a need for research that quantifies the agricultural implications of the urban heat island and different urban microclimates.

The purpose of this research was to explore the possibility of growing, in Toronto, warmer-climate crops that would not perform well in the surrounding rural areas. To achieve this, the UHI was separated from global climate change by comparing historic weather data from Toronto to that of a rural control. GDDs, Frost Free Days (FFDs), predicted budbreak date, and winter hardiness