Urban Production of Fruits and Vegetables: Current Estimates and Opportunities for Growth in Ramsey County, Minnesota

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Abstract

Population growth and the progression of climate change will require a more sustainable, resilient, and equitable food system. A more sustainable food system may include shifting where food is grown, such as growing more perishable and intensive crops (fruits and vegetables) closer to large population centers. Production of fruits and vegetables near urban centers has the potential to offer a wide array of benefits, including increasing access to healthy food and reducing food waste. This project used USDA data to quantify the current production of fruits and vegetables in Ramsey County, Minnesota and estimate potential production capacity if fruits and vegetables were to be grown on farmland currently used to grow grains or raise animals, on land currently used for parking lots, and with rooftop gardens. These estimates were compared to the quantity required to meet the population of Ramsey County's needs based on the Dietary Guidelines for Americans to illustrate potential pathways to meeting the nutritional needs of urban areas with an equitable, low-carbon food system. Current (2017) production of fruits and vegetables in Ramsey County meets its population's needs for just under 4 days per year, while the potential production methods considered were estimated to add an additional 32.4 days of meeting the population's needs. These low current and potential production figures emphasize the continued importance of rural areas as the primary producers of food for urban populations, while also illustrating the potential to significantly increase food production in urban areas and improve food system resiliency through diversifying where and how crops are grown.

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Introduction

A wide range of solutions is required to meet the nutritional needs of a growing global population while reducing the environmental impacts of food systems. Conventional agricultural systems are highly productive (USDA National Agricultural Statistics Service, n.d.), but result in widespread soil erosion (Lal, 1998), nutrient loss to the environment (Oenema *et al*., 2005), food waste (Lipinski *et al.*, 2013), greenhouse gas emissions (IPCC, 2019), air quality issues (Domingo *et al*, 2021), and poor diets (IPCC, 2019). Food production is essential to human survival, so some environmental impact may be acceptable, but the environmental impacts of agriculture cannot be ignored altogether. Meeting the goals of the Paris Agreement will require a reduction in food system emissions (Clark *et al.*, 2020). Agriculture is responsible for 21 to 37% of global greenhouse gas emissions (IPCC, 2019). Agriculture also puts strains on water systems through the usage of large amounts of freshwater (FAO, 2011), and pollutes surface and ground waters through nutrient leaching (Oonema *et al.*, 2005). Agriculture uses approximately half of all habitable land on Earth (Ellis *et al.*, 2010), creating conflicts between the housing needs of growing populations, increasing food demand, and natural habitats that maintain biodiversity and sequester carbon. At the same time, productive agricultural land is being lost to erosion, salinization, development, and other factors (FAO, 2011). Losses of some agricultural land may be able to be offset by shifting some food production into urban areas.

While the argument is often made that local food has lower carbon emissions, food transportation emissions are a very small percentage of overall food system emissions, and shifting diets to include fewer animal products has a far bigger impact on reducing emissions than eating local food (Poore and Nemecek, 2018; Sandstrom *et al.*, 2018). In many cases, producing food locally out of season using heated greenhouses leads to much higher emissions than importing the same food from a region where it is in season (Hospido *et al.*, 2009; Carlsson-Kanyama *et al.*, 2003). Additionally, production of food in urban areas may shift agricultural emissions closer to population centers, where they may cause harm to a greater number of people (Goodkind *et al.*, 2019). For these reasons, a completely local diet is undesirable from an environmental perspective, as well as being impractical for many people, due to climate, time, and income constraints. However, a partially local diet that focuses on producing fruits and vegetables locally during the growing season may offer many benefits, including a modest reduction in transportation emissions, a reduction in food waste, strengthening local economies, and increasing consumer involvement in agricultural systems. The expansion of global trade networks has led to increased disconnection between populations and the land and water that produces their food (D'Odorico *et al.*, 2014), which local food production may help address. Urban agriculture can have a variety of economic benefits for urban populations, including increasing incomes, creating jobs, offsetting food expenses, and increasing food security (Ackerman *et al.*, 2014). Reduction in food waste at the consumer level is a major potential benefit of urban agriculture. Food waste accounts for an estimated 6% of global greenhouse gas emissions (Poore and Nemecek, 2018). On a weight basis, 64% of all food loss and waste globally is fruits and vegetables (44%) or roots and tubers (20%) (Lipinski *et al.*, 2013). In North America and Oceania, 61% of food waste occurs at the consumer level (Lipinski *et al.*, 2013). Food waste at the consumer level is caused by a wide variety of factors - notably a lack of desire to reduce food waste - which is partially the result of an unsustainable food system that produces food at low costs which do not accurately reflect the environmental costs of food production (Aschemann-Witzel *et al*., 2015). Increasing connection between consumers and food production systems, such as by increasing consumption of local foods, has been suggested as a potential solution to food waste at the consumer level (Aschemann-Witzel *et al.*, 2015).

In addition to having high emissions overall (regardless of transport distance), animal products typically require large amounts of land and may result in significant air quality concerns for populations living nearby (Domingo *et al.*, 2021), making them better suited for production in rural areas. Fruits and vegetables, which typically produce higher yields per land area and result in the lowest air pollution damages on a weight basis of any food category (Domingo *et al.*, 2021) - in addition to being highly perishable - are well suited to production in urban areas, especially during the growing season.

The EAT-Lancet Commission's planetary health diet, which is designed to promote human health while reducing food system emissions and meeting the needs of a growing population, recommends that global consumption of fruits, vegetables, legumes, and nuts increase by more than 100% by 2050 to transition to healthy diets while feeding a growing population and reducing food system emissions (Willett *et al.*, 2019). The recommended dietary changes, which include reducing consumption of red meat and sugar in addition to increasing fruit and vegetable consumption, are estimated to have the potential to avert 10.8 to 11.6 million deaths per year globally (Willett *et al.*, 2019).

In the 1970s, the United States was a net exporter of fruits and vegetables (Johnson, 2016). Today, the United States is a net importer of fruits and vegetables, importing $11.4 billion more fruits and vegetables than it exported in 2015 (Johnson, 2016). The main sources of fruits and vegetables imported in 2015 were Mexico (44%), Canada (12%), and Chile (8%) (Johnson, 2016). Interestingly, nearly 12% (by monetary value) of the total fruit and vegetable imports to the United States in 2015 was one single crop: bananas (Johnson, 2016). Domestic demand for specific types of fruits and vegetables - like bananas - that cannot easily be grown in the United States is likely to complicate efforts to increase urban agriculture and local food consumption. This may be an additional reason to aim for a partially local diet instead of a completely local diet. Within the US, over 40% of vegetable acreage is located in California (Keough, 2022). California produces over one-third of the United States' vegetables and more than two-thirds of the US's fruits and nuts (Spiegel, 2021). California's food production systems have experienced a number of devastating environmental challenges, including drought, flooding, heat, and wildfires (Spiegel, 2021). As climate change progresses and these challenges get worse, there may be a need to shift production within the United States to regions less plagued by wildfires, drought, and limited freshwater.

Ramsey County, Minnesota is a largely urban county, hosting the state capital of Saint Paul. In 2017, only 0.5% of Ramsey County's land was classified as agricultural (Gunderson *et al.*, 2019). Only two counties in Minnesota had a smaller percentage of agricultural land, which - in addition to Ramsey County being the smallest county in Minnesota - means Ramsey County has less cropland than all but one other county[1] in Minnesota (Gunderson *et al.*, 2019). Agricultural production has been declining in the region due to increasing development. In 1990, 18,254 acres (16.8%) of land in Ramsey County was classified as agricultural or vacant (Minnesota Land Management Information Center, 1990). By 2017, that value had declined significantly to only 645 acres (0.5%) (USDA National Agricultural Statistics Service, 2017a; Gunderson *et al.*, 2019). In 2017, Ramsey County's 645 total acres of agricultural land included 108 acres of fruits and vegetables, 324 acres of additional crops (primarily corn, soy, and wheat), 90 acres of pastureland, and 123 acres of woodland (USDA National Agricultural Statistics

[1] The county with the lowest area of cropland is Cook County, located in the far northeastern corner of Minnesota.

Service, 2017a).

There are many potential pathways for increasing urban agriculture, with some of the simplest involving producing food outdoors on large areas of land that are unused or being underutilized, including cropland, pastureland, parking lots, and rooftops.

In 2017, Ramsey County contained 324 acres of cropland not used to produce fruits and vegetables, but instead used for forage crops and grains (USDA National Agricultural Statistics Service, 2017a). While these products are important components of human and/or animal diets, they are able to be stored longer-term than fresh fruits and vegetables and can be transported using lower-emissions methods due to longer shelf life. Given the high population density of Ramsey County, to maximize emissions reductions and minimize food waste, using that cropland for additional production of fruits and vegetables may offer significant benefits.

In 2017, Ramsey County's farmland included 123 acres of woodland and 90 acres of pastureland (USDA National Agricultural Statistics Service, 2017a). While converting woodland into land suitable to grow fruits and vegetables would be possible, it is likely to be a difficult endeavor and would involve deforestation and loss of wildlife habitat, and thus woodland is not considered as potential production area in this analysis. Pastureland may also present barriers to growing crops, such as uneven terrain or poor soil, but it is likely to be much more suitable for growing fruits and vegetables than woodland.

A significant amount of urban land is used for parking lots, on which cars sit unused for the vast majority of the time, only being actively used a small percentage of the time. Ramsey County's ArcGIS database includes estimates of total land area used for parking structures, categorized into paved and unpaved parking lots (Ramsey County GIS Portal, 2022). Ramsey County includes a total of 684.5 acres of parking lots, including 620.5 acres of paved lots and 64 acres of unpaved lots (Ramsey County GIS Portal, 2022). Converting parking lots into growing spaces would be a much bigger undertaking than using existing farmland, but it could be done by bringing in soil to place on top of the existing lots, or removing the pavement to expose the existing soil. As urban areas transform transportation systems to reduce emissions, expanded use of public transportation, shared vehicles, and biking and walking paths may free up some of the land currently used as parking lots. It is unlikely that all parking lots would ever be converted into growing spaces, but to illustrate maximum potential production, all parking lot areas will be considered potential growing spaces in this analysis.

Rooftop gardens offer the potential to produce food on top of a building being used for other purposes. They can offer many benefits, including lowering energy costs, producing food, reducing heat island impacts, increasing roof lifespan, and stormwater retention (Minnesota Pollution Control Agency, 2022b). However, the soil, water, and plants required for rooftop gardens can be very heavy, generally ranging from 10 to 300 lb/ft^2 depending on the depth of soil and other materials used (Minnesota Pollution Control Agency, 2023). The existing roofs on many buildings likely could not sustain the additional weight without collapsing. Rooftop gardens also require a relatively flat roof. In general, roofs with a slope greater than 9.5 degrees will require special reinforcement to establish a rooftop garden, and roofs with slopes greater than 40 degrees should not be used at all for rooftop gardens (Minnesota Pollution Control Agency, 2023). To provide a simplified estimate of the scale of rooftop gardens in Ramsey County, this analysis considered all parking garages as potential sites of rooftop gardens, as well as all non-residential roofs with an area of 20,000 ft^2 or greater.

This study aims to quantify the current production of fruits and vegetables in Ramsey County and estimate potential production using several different methods of urban food production: shifting agricultural land use, creating growing spaces on parking lots, and rooftop gardens. Fruits and vegetables are a critical component of healthy human diets, and their value extends far beyond calories. Quantifying fruit and vegetable production using calories is likely to undervalue their benefits, which include less-easily-quantifiable fiber, vitamins, antioxidants, and many other important compounds. To simplify yet not understate the value of fruits and vegetables to human diets, this study aims to quantify fruit and vegetable production in terms of serving sizes, which is a widely recognizable concept by the public and does not undervalue fruits and vegetables as compared to calorically dense foods like grains or meat.

Methods

Nutritional Requirements of Ramsey County, MN

The population of Ramsey County, MN was retrieved from the US Census Bureau database, using the most recent data available. Though many people commute to and eat in Ramsey County who do not reside there, to simplify this analysis only residents of Ramsey County were considered.

The Dietary Guidelines for Americans for 2020-2025 advise that each person following a standard 2000-calorie diet should consume two and a half cup-equivalents (servings) of vegetables and two cup-equivalents (servings) of fruits per day (Dietary Guidelines for Americans, 2020). One cup-equivalent is defined as one cup of fresh or cooked non-leafy vegetables or fruits or two cups of leafy vegetables. Fruit and vegetable intake recommendations do vary by age, gender, calorie requirements, and other factors, but to simplify this analysis the standard recommendation of two and a half servings of vegetables and two servings of fruits will be used for all residents. The population of Ramsey County was multiplied by the serving recommendations to determine total fruit and vegetable servings required per year (Fig. 1).

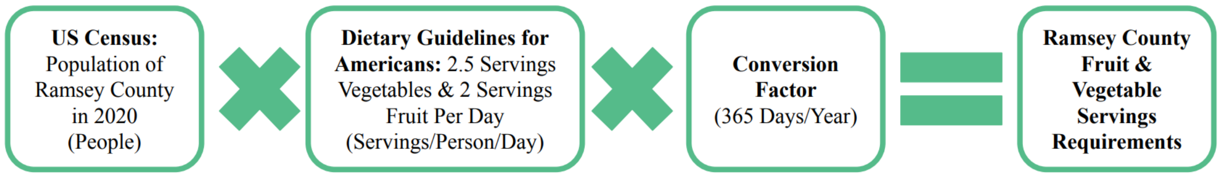

Figure 1. Process for determining total fruit and vegetable servings requirements.

Current Food Production in Ramsey County, MN

Given the decline in agricultural production in Ramsey County from 2012 to 2017 (USDA National Agricultural Statistics Service, 2017f), it is assumed that the number of farms and total vegetable production has continued to decline in the region since 2017. However, since no more recent data was available at the time of this analysis, the USDA Agricultural Census data from 2017 was used to estimate current food production in Ramsey County.

Area of Fruit & Vegetable Production

In 2017, Ramsey County included a total of 18 acres planted with fruit trees, both of bearing and non-bearing age (USDA National Agricultural Statistics Service, 2017d). Sufficient data was not available to distinguish between the acres of bearing-age fruit trees and non-bearing age, so the total acres planted with fruit trees was used to estimate current production. The county-level data available from NASS Quick Stats indicated that this 18 acres included 15 acres of apples, 2 acres of plums, and an undisclosed amount[2] of apricots, tart cherries, and grapes (Table A1). It was assumed that the remaining 1 acre included ⅓ acre each of apricots, tart

[2] Data is undisclosed by the USDA when there are so few producers that disclosing it may reveal confidential information about an individual producer.

cherries, and grapes.

In 2017, Ramsey County included 2 total acres of berry crops (USDA National Agricultural Statistics Service, 2017e), all of which were categorized as “other berries,” not including any aronia berries, blackberries, dewberries, blueberries, cranberries, currants, elderberries, loganberries, raspberries, or strawberries (USDA National Agricultural Statistics Service, 2017b). Though there is no disclosed list of what berry crops are part of “other berries,” it may include specialty berry crops that grow well in Minnesota such as gooseberries, kiwiberries, or serviceberries (University of Minnesota Extension, n.d. b; Zuzek *et al.*, 2018).

A total of 86 harvested acres of vegetables, melons, and potatoes was recorded in Ramsey County in 2017 (USDA National Agricultural Statistics Service, 2017g). This total included an undisclosed amount of eggplant, okra, green peas, and turnip greens, however, since the total disclosed acres was equal to the total vegetable acres, the undisclosed values were assumed to be approximately zero (Table A2).

In 2017, Ramsey County also produced vegetables and herbs in greenhouses, with 1.7 acres of total greenhouse vegetable production (USDA National Agricultural Statistics Service, 2017c). Most of this production was tomatoes, while the remainder was simply categorized as “other vegetables and herbs” with no details as to which vegetables were grown (Table A3). In Minnesota, greenhouses are typically used to extend the short growing season (University of Minnesota Extension, n.d. a). Aside from tomatoes, some of the most common crops to grow in Minnesota greenhouses are cold-tolerant lettuce, herbs, Asian greens, and Brassicas (cabbage, kale, broccoli, etc) (University of Minnesota Extension, n.d. a).

Estimated Crop Yields

Average yields for each crop were needed to convert land area of production into servings of fruits and vegetables (Table A4). First, the USDA NASS Quick Stats database was searched for available yield data. When available, Minnesota average yield data was used (Fig. 2). When yield data for Minnesota was not available, data for a nearby state with similar climate (Wisconsin, Michigan, Iowa) was used. When no nearby states had available data, national data was used. When multiple years of data were available, all data available between 1998 and 2022 was averaged to estimate yield.

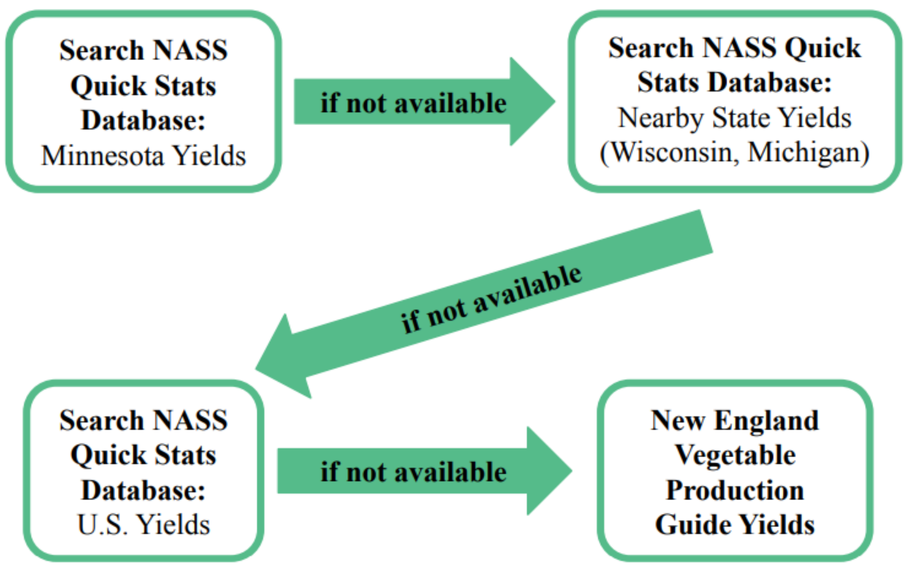

Figure 2. Process for obtaining yield estimates for each crop.

There was yield data available for most fruit and vegetable crops in the NASS Quick Stats Database (Table A4). There was no yield data available for herbs, green onions, parsley, Chinese peas, rhubarb, tomatoes under protection, or turnips. For those crops, estimated yields were obtained from the New England Vegetable Management Guide Approximate Yields Table, using the mid range ("good") yields (New England Vegetable Management Guide, n.d.).

Estimated Weight per Volume of Fruits & Vegetables

To convert yields (in pounds per acre) into serving sizes, weight per volume of each crop was obtained from the USDA's FoodData Central Online Database (USDA Agricultural Research Service. n.d.). Data for raw, chopped or sliced fruits and vegetables was used to best estimate serving sizes (Table A5).

Total Servings of Fruits and Vegetables Produced in Ramsey County in 2017

To calculate total servings of fruits and vegetables produced, areas of production (Tables A1-A3) were multiplied by yield estimates to obtain production by weight for each crop (Table A4). Production by weight was divided by the weight to volume conversions and cups per serving for each crop to obtain servings produced (Table A5). For all non-leafy fruits and vegetables, one cup is equivalent to one serving (Dietary Guidelines for Americans, 2020). For leafy greens, which includes herbs (basil), kale, lettuce, parsley, green onions, and other greenhouse vegetables, two cups is equivalent to one serving (Dietary Guidelines for Americans, 2020). Using the standard recommendation of 2 servings of fruits and 2.5 servings of vegetables per day (Dietary Guidelines for Americans, 2020), total servings produced were divided by Ramsey County's population and 365 days/year to obtain more meaningful values (Table 2). The overall process for calculating total servings per year is illustrated in Figure 3.

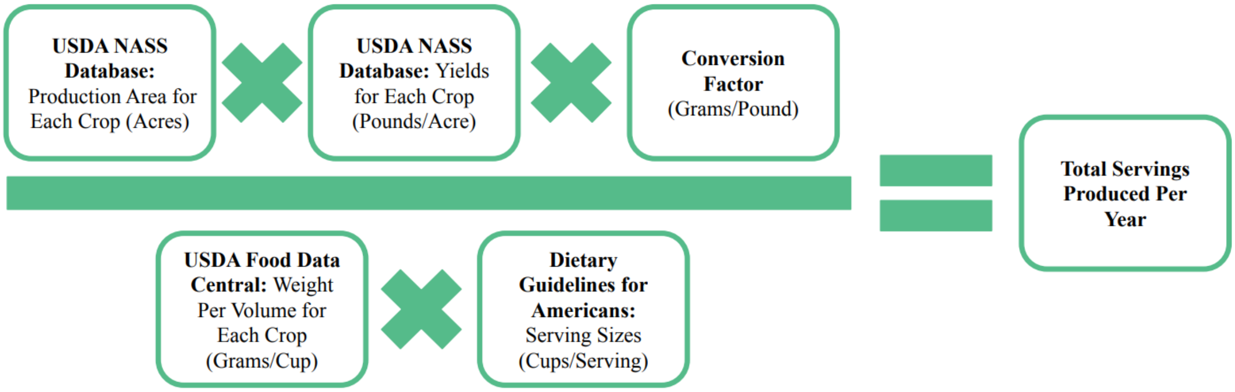

Figure 3. Process for calculating total servings of fruits and vegetables produced.

<u>Estimating Potential Production Capacity</u>

Remaining Cropland

To estimate potential fruit and vegetable production on cropland not currently used for fruits and vegetables, the crop distributions and yields estimated above were scaled up for the new quantity of land, assuming the same proportion of each crop produced and the same yields. The calculated values of servings of fruits and vegetables currently produced per acre (Table 2) was multiplied by the remaining 324 acres of cropland to obtain fruit and vegetable production potential (Table 3).

Pastureland

The estimates of fruits and vegetables produced per acre (Table 2) were multiplied by the 90 acres of pastureland to obtain potential fruit and vegetable production (Table 3).

Parking Lots

The estimates of fruits and vegetables produced per acre (Table 2) were multiplied by the

684.5 acres of parking lots to obtain potential fruit and vegetable production (Table 3).

Rooftop Gardens

To provide a simplified yet reasonable estimate of rooftop garden potential, building footprint areas and building classifications were used to estimate which buildings were suitable for rooftop gardens. Ramsey County's ArcGIS database includes building footprints of parking ramps (Ramsey County GIS Portal, 2018). The parking ramps included do not overlap with the parking lots shown in the parking structures database (Ramsey County GIS Portal, 2022). Ramsey County includes a total of 7.85 acres of parking ramps, most of which have a sturdy, flat top level that could sustain the weight of a rooftop garden (Ramsey County GIS Portal, 2018).

Ramsey County includes an additional 336.2 acres of building footprints (9619 total buildings) classified as non-residential (Ramsey County GIS Portal, 2018). This includes schools, office buildings, restaurants, hospitals, stores, and other non-residential buildings. Some of these buildings are likely to be currently suitable or suitable after modifications for rooftop gardens, however many of these buildings have sloped and/or weak roofs not designed for the weight of a rooftop garden. Unsuitable buildings were eliminated based on roof size. Rooftop gardens are expensive to install, and it is likely that small projects may not be financially justified, especially when compared to growing food on rural agricultural land. Per-square-foot costs are estimated to decrease by at least a factor of three when roof size increases from 1000 ft^2 to 20,000 ft^2 (Minnesota Pollution Control Agency, 2022a). The dataset was filtered to only include roofs with an area of 20,000 ft^2 or greater, which resulted in 50 remaining buildings (0.73 acres total). These buildings all were between 645 and 2810 feet in length, with widths between 15 and 38 feet (Ramsey County GIS Portal, 2018). Since no data on roof slope was available, it was assumed that all of these non-residential buildings with roof areas greater than or equal to 20,000 ft^2 were suitable for rooftop food production. In total, it was estimated that 8.58 acres of rooftop gardens could potentially be created in Ramsey County between parking ramp roofs and other non-residential roofs. The estimates of fruits and vegetables produced per acre (Table 2) were multiplied by the 8.58 acres of suitable roofs to obtain potential fruit and vegetable production (Table 3).

Results

Nutritional Requirements of Ramsey County, MN

As of the 2020 Census, Ramsey County, MN had a population of 552,352 people (United States Census Bureau, 2020). For the population of Ramsey County, 504 million servings of vegetables and 403 million servings of fruits would be required annually to meet the U.S. Dietary Guidelines (Table 1).

Table 1. Servings of fruits and vegetables required per year for Ramsey County population to meet Dietary Guidelines for Americans.

Fruits	Vegetables	Fruits & Vegetables
403,000,000	504,000,000	907,000,000

Current Food Production in Ramsey County, MN

Current production of fruits and vegetables in Ramsey County includes approximately 8.6 million servings of vegetables and 0.96 million servings of fruits per year (Table 2). When divided by the population size and days per year, this would meet the population’s vegetable needs for 6.2 days per year, and fruit needs for 0.9 days per year (Table 2). The calculated values of servings produced per acre indicate that vegetables are over twice as productive per land area as fruits, though this figure was calculated based on the specific fruit and vegetable crops grown in Ramsey County (Table 2).

Table 2. Estimated current production of fruits and vegetables in Ramsey County.

	Total Fruit & Vegetable Servings	Vegetable Servings	Fruit Servings
Total Production Per Year (servings)	9,590,000	8,550,000	965,000
Total Production Per Person Per Year (servings/person)	17.4	15.5	1.7
Total Days Per Year of Meeting Population's Required Servings/Day (days)	3.9	6.2	0.9
Production Per Acre (servings/acre)	89,000	99,900	43,900

Estimating Potential Production Capacity

Using the remaining cropland in Ramsey County to grow fruits and vegetables could increase the days per year of meeting the population's needs by an additional 18.6 days for vegetables and 2.6 days for fruits (Table 3). Pastureland could provide an additional 5.2 days of vegetables and 0.7 days of fruits (Table 3). Parking lots were the largest additional source of land in this analysis, and could increase production by 39.4 additional days of meeting vegetable needs and 5.5 days of fruit needs (Table 3). Rooftop gardens could add 0.5 days of vegetable production and 0.1 days of fruit production (Table 3).

Table 3. Potential additional production.

	Remaining Cropland	Pastureland	Parking Lots	Rooftop Gardens
Total Fruit & Vegetable Production Per Year (servings)	28,800,000	8,010,000	60,900,000	764,000
Total Vegetable Production Per Year (servings)	25,700,000	7,150,000	54,400,000	682,000
Total Fruit Production Per Year (servings)	2,890,000	804,000	6,120,000	76,700
Total Fruit & Vegetable Production Per Person Per Year (servings)	52.2	14.5	110	1.4
Total Vegetable Production Per Person Per Year (servings)	46.6	12.9	98.5	1.2
Total Fruit Production Per Person Per Year (servings)	5.2	1.5	11.1	0.1
Total Days Per Year of Meeting Population's Required Fruit & Vegetable Servings/Day (days)	9.5	2.6	20.1	0.3
Total Days Per Year of Meeting Population's Required Vegetable Servings/Day (days)	18.6	5.2	39.4	0.5
Total Days Per Year of Meeting Population's Required Fruit Servings/Day (days)	2.6	0.7	5.5	0.1

When considered as a percentage of annual fruit and vegetable needs met, current production meets 1.1% of Ramsey County's needs (Fig. 4). The four additional types of production considered could meet an additional 8.9% of Ramsey County's needs (Fig. 4). This leaves 90% of Ramsey County's fruit and vegetable needs to be met by production occurring outside the county (Fig. 4).

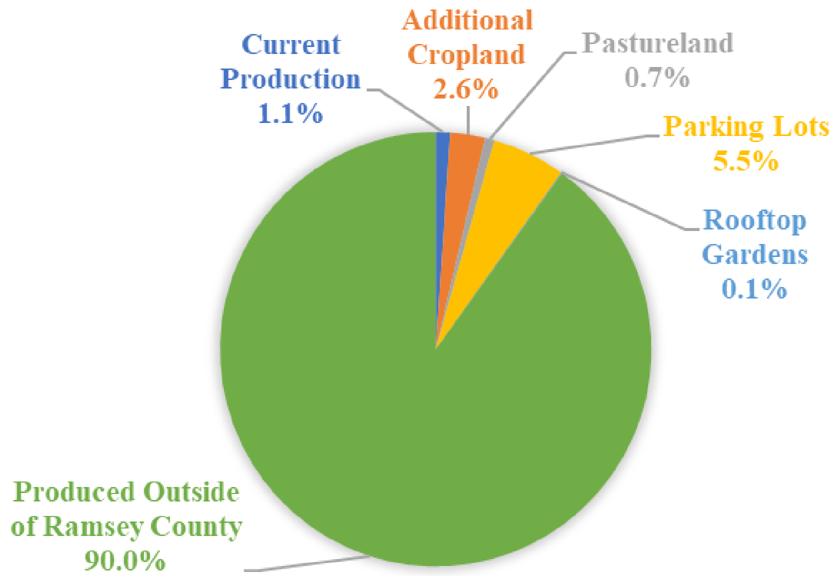

Figure 4. Proportion of fruit and vegetable requirements met by current and potential production systems in Ramsey County.

Discussion

The low food production capacity of urban areas like Ramsey County illustrates the critical importance of rural areas for producing the majority of the food required by urban populations, both now and in the future. Urban agriculture as it currently stands is unlikely to ever fully (or even mostly) replace rural agriculture, though it appears to have significant room to expand and there are many notable benefits of doing so.

The production estimates in this study present an approximate picture of current and future production, but there are many assumptions that were made that may introduce some error. It was assumed that all acres with fruit trees were producing fruit at the yields expected at maturity. However, fruit trees do not bear fruit for several years after planting (depending the species, variety, and other factors), and a portion of the land planted with fruit trees is likely non-bearing in any given year. It was also assumed that only one crop is produced on each area of land per year, which may not be true, especially in vegetable production systems where some crops require less than 6 weeks from planting to harvest (baby lettuce, radishes, etc) (Schuh & MacKenzie, 2022).

Perhaps the biggest source of error in this study is that it does not account for food waste. Yield data provided by the USDA includes unavoidable food waste, which are portions of the crops that are not edible or that consumers will generally not eat (e.g. apple cores, carrot tops, melon rinds). The weight to volume conversion factors used to convert yield data into serving sizes (Table A5) assume that the entire weight of the crop (as measured by yield) is consumable. This will result in an overestimation of servings provided by current and potential crop production. Additionally, a large portion of fruits and vegetables are wasted, including at the consumer level, and this is not likely to end simply because the food is produced locally (Lipinski *et al.*, 2013). This means that the current and potential production figures in this study likely overestimate how many servings Ramsey County's production could actually provide.

Since USDA production data is only available once every five years, this analysis relied on the production data and crop distribution from 2017 as an approximation for a typical recent year. However, it is unknown if 2017 was indeed a typical production year, or if acres of each crop grown in 2017 was significantly different from most recent years. It is also possible that vegetable production and available agricultural land in Ramsey County has declined since 2017, but since 2022 data was not released at the time of this analysis, 2017 data was used.

This analysis also assumed that potential production would involve the same fruit and vegetable crops grown in the same proportions as they were grown on cropland in 2017. It is important to note that some crops, such as fruit trees, would not actually be suitable for some production methods, like rooftop gardens. Since this study calculated that fruits on average produce less than half as many servings per acre as vegetables (Table 2), this is likely to result in an underestimate of production potential.

This study assumed equal yields between the farm production data obtained from the USDA and all methods of urban production. In reality, yields vary widely based on geographic location, temperatures, water and nutrient availability, and method of production. A meta-analysis by Payen *et al.* (2022) found that urban agricultural yields were on average equal to or greater than conventional farm yields. Some of the greatest differences in yields were observed between types of growing systems; for example, hydroponic tomatoes had much higher yields than tomatoes grown in soil (Payen *et al.*, 2022). This suggests that the production estimates presented in this study may be lower than actual potential production, and larger increases in urban food production may be possible using alternative production methods, such as hydroponics.

Additionally, this study only considered fruit and vegetable needs by the population of Ramsey County. Fruits and vegetables are only a portion of a complete diet, and additional foods such as grains, legumes, nuts, and animal products would also be required. The current and potential production figures in this analysis refer only to fruit and vegetable requirements. While there is significant room to expand fruit and vegetable production in urban areas, this represents only a very small percentage of the total food needs of urban populations.

Perhaps the easiest method of increasing urban production of fruits and vegetables is shifting agricultural land use, which presents very few infrastructure or zoning barriers and could increase the fruit and vegetable production in Ramsey County from 1.1% to 4.4%. Slightly more complicated, yet still relatively simple, methods of urban agriculture like rooftop and parking lot gardens present larger economic barriers but still relatively few infrastructure challenges. The relatively simple and achievable methods of urban food production described in this study represent a floor of the potential of urban agriculture. Many more innovative, complicated methods of growing food in urban spaces are possible and could increase the estimates found in this study significantly. Though this study found a low production capacity of urban agriculture, there is still substantial room to expand production through methods not considered in this analysis, including the University of Minnesota research fields, home gardens, indoor food production, shifting diets, and deep winter food production.

University of Minnesota Research Fields

This study included all land considered agricultural by the USDA's Census of Agriculture. However, in Ramsey County, the University of Minnesota's Minnesota Agricultural Experiment Station (MAES) includes 181 acres of cropland (Andrew Scobbie, personal communication, April 25, 2023). This cropland is included in the USDA's Census of Agriculture dataset, so it is included in this analysis (Andrew Scobbie, personal communication, April 18, 2023). However, crops produced on the research fields are not sold to consumers, so they are not really available to meet consumers' fruit and vegetable needs. In 2017, the MAES research fields included 11.9 acres of fruit and vegetable crops and 169.1 acres of non-fruit and vegetable crops, including animal feed, grains, and turfgrass (Andrew Scobbie, personal communication, April 25, 2023). If this area was removed from the current and potential production analysis, the current production of fruits and vegetables would decrease by 11% and the potential production on additional cropland would decrease by 52%. This area of land was left in this analysis to illustrate the potential production capacity of Ramsey County. There is a significant opportunity to increase availability of local fruits and vegetables through improving management of the crops produced on the research fields, such as by donating the crops produced to food shelves in the area.

Home Gardens

This study did not consider home garden production, largely due to the complicated nature of estimating it. Many yards include large shade trees, which impede the growth of fruits and vegetables, but are valuable to homeowners and the public for other services they provide (protection from heat and sun in the summer, energy efficiency, recreation, increased home values). Additionally, many homeowners lack the interest, time, or resources to grow their own food, or have other preferred uses for their yards that food production would interfere with. A recent study of Minneapolis and St. Paul, Minnesota estimated production of fruits and vegetables by home gardens using both ground surveys and satellite imagery (Ramaswami *et al.*, 2022). They determined that home gardens in Minneapolis and St. Paul currently produce 290 to 316 tons of vegetables annually (Ramaswami *et al.*, 2022). This meets only 0.5% of vegetable demand, using a current retail demand of vegetables in the Twin Cities of 60,942 tons (Ramaswami *et al.*, 2022). While overall production is small, participation in gardening has been increasing, from roughly 5% of Twin Cities households gardening in 2017 to 8% in 2020 (Ramaswami *et al.*, 2022). If this trend continues, home gardens may prove to be a more important source of local fruits and vegetables. Interestingly, this study found that yard size was not a significant predictor of the size of a garden, indicating that the limiting factor for home garden production is not land availability (Ramaswami *et al.*, 2022).

Indoor Food Production

Perhaps one of the most promising methods of urban agriculture was not included in this study due to the complexity of estimating it: indoor food production. Indoor food production involves growing food inside of buildings that are either used for another purpose or no longer used. The primary benefit of growing food in buildings used for other purposes is that the buildings are already heated and cooled to temperatures comfortable for humans, and thus the only additional electricity required is for lighting and water pumps. Previous research that has calculated higher emissions for food grown out of season in greenhouses as compared to imported food found that the increase in emissions was largely due to heating (Hospido *et al*., 2009). Spaces that are already heated for human comfort may be able to produce food out-of-season with fewer emissions than imported food. Many buildings may be suitable for this type of indoor food production, including schools, community centers, homes, and office buildings.

Food can also be produced indoors in buildings that are no longer used for another purpose. This may result in additional heating costs, though it may still offer benefits over conventional agriculture, including reduced water use (Broom, 2021). In the United Kingdom, portions of an underground World War II bunker have been converted into an indoor farm (Broom, 2021). In St. Paul, Minnesota, Urban Organics established a vertical indoor farm in a former brewery, and produced leafy greens and fish using aquaponics for about six years (Wisconsin State Farmer, 2017). However, in 2019, the facility was shut down by its parent company Pentair because "the business model did not meet our expectations" (Painter, 2019). In 2021, Kalera, a company with successful indoor vertical farms in Florida and Georgia, purchased a facility in St. Paul to convert into a vertical farm for producing leafy greens (AgriTech

Tomorrow, 2021). Overall, indoor food production in urban areas through methods like vertical farming and hydroponics seems to be growing. However, it is still largely constrained to leafy greens on a commercial scale (Broom, 2021; Painter, 2019; AgriTech Tomorrow, 2021).

Shifting Diets

Shifting diets to include more urban food production is likely to involve much less flexible diets than many Americans are accustomed to. Even in areas that can grow food outdoors year-round, there are still limitations on what times of the year each crop can be grown. Today, nearly identical food offerings are available in United States grocery stores throughout the year, regardless of what crops are in season in each region. Consuming more local food will require some shifting of diets, with foods being consumed primarily or only during the time when they are in season. In places like Minnesota, a very short growing season means that throughout the long winters, only a few locally-grown crops are still available: potatoes, squash, onions, carrots, and other similar storage crops. These dietary changes may be inconvenient and frustrating for consumers who prefer a wider variety of food. Additionally, some foods (such as tropical fruits) simply cannot be grown outdoors at all in Minnesota's climate, and would not be available at all if diets were to be completely local. These reasons, in addition to the higher emissions of producing food out of season in traditional heated greenhouses, suggest that a partially local diet may be most preferable, with local food primarily consumed during the growing season.

Deep Winter Production Methods

Minnesota's extremely cold winters may seem incompatible with food production outside of heated greenhouses or buildings, but many historical methods and current areas of research indicate that there may be more potential to produce food throughout the winter than is typically assumed. Additionally, the range of crops that can survive Minnesota winters can be widely expanded with a thorough understanding of microclimates, plant physiology, and protective structures.

In his book *The Winter Harvest Handbook: Year Round Vegetable Production Using Deep-Organic Techniques and Unheated Greenhouses*, Eliot Coleman describes the techniques he uses to grow vegetables throughout the winter in Maine without using any additional heat or light. Most importantly, Coleman selects plants that are cold tolerant, including lettuce, kale, carrots, and others (Coleman, 2009). Such cold-tolerant plants are already adapted to thrive in low light, cold conditions. Coleman provides additional protection by covering the plants with floating row covers, which are located inside of high tunnels for additional protection (Coleman, 2009). Though Coleman's techniques may not be completely transferable to the harsher winters of Minnesota, there is likely much that can be adapted from them to the winter conditions of Minnesota.

The University of Minnesota Extension Regional Sustainable Development Partnerships and the College of Design's Center for Sustainable Building Research have developed and tested two designs of deep winter greenhouses (University of Minnesota Extension, n.d. a). The designs are different from traditional greenhouses in that they are not covered in glazing material[3] on all sides. Instead, only the south side of the greenhouses are glazed, and the north side - which only collects a very small portion of light in traditional greenhouses - is covered with insulation instead (University of Minnesota Extension, n.d. a). Deep winter greenhouses may be able to

[3] Glazing material is material that allows light to pass through, such as glass or clear plastic. While it is useful for obtaining light, glazing material allows significant heat to be lost to the environment compared to insulated walls.

operate without additional heating in some environments, but designs for Minnesota typically include an additional heating element for occasional use on extremely cold winter days (University of Minnesota Extension, n.d. a). Like Eliot Coleman's winter production systems, deep winter greenhouses are designed to produce cold-tolerant crops, primarily salad greens, like lettuce, mustard greens, and kale (University of Minnesota Extension, n.d. a).

Following the establishment of the Soviet Union in 1925, significant efforts went to developing self-sufficiency of expensive, imported food crops, including citrus (De Decker, 2020). Citrus plants are extremely frost-tender, typically being significantly damaged or killed by even short-term exposure to freezing temperatures (De Decker, 2020). Nevertheless, by 1950, the Soviet Union had 30,000 hectares of citrus trees (including mandarins, lemons, and oranges) and produced 200,000 metric tons of citrus annually (De Decker, 2020).[4] This included production in regions with winter low temperatures of -30°C (-20°F) (De Decker, 2020), which is very similar to the winter low temperatures in Ramsey County, MN. The success of citrus production in an extremely cold climate was the result of breeding for cold tolerance, pruning to keep the plants less than 1 foot tall (so they remained in a mild microclimate), and growing the plants in trenches up to 6 feet belowground (De Decker, 2020). Citrus trees planted in trenches were protected from wind and temperature extremes, and in the winter, the trenches were covered with a layer of wood and straw to maintain the heat from the soil (De Decker, 2020). This system allowed citrus to be produced in extremely cold regions without any additional heat or light sources. In regions near the Arctic circle, where additional heating was required to keep citrus alive, trees were grown in pots inside already-heated buildings, such as schools, apartments, and offices (De Decker, 2020).

[4] This is equivalent to a yield of 5,950 lbs/acre. For comparison, orange yields in Florida generally range from 12,000 to 33,000 lbs/acre (NASS Quick Stats Database search, 1978-2022).

Today, roughly 30 miles northeast of Ramsey County, in Taylors Falls, MN, Dan Shield of Stone Creek Farm has developed a system of growing peaches that requires no additional light and only small amounts of additional heating (CBS Minnesota, 2022; Shield, 2023). Peaches are generally considered far too cold sensitive to be grown in Minnesota, but Shield has developed a system that has successfully produced peaches for 10 years (Shield, 2023). Peaches are planted in a high tunnel, which is covered with an additional layer of silage tarp in the winter, blocking roughly 95% of the light and helping to keep heat in (Shield, 2023). Only on extremely cold winter days is additional heat added to the high tunnel using heat cables (CBS Minnesota, 2022). Blocking winter light is critical to the success of this system, just as it was in the Soviet Union's citrus production system (Shield, 2023; De Decker, 2020). While not well understood, it is believed that blocking winter light causes tree metabolism to slow down significantly, interfering with dormancy processes and increasing cold tolerance (De Decker, 2020; Shield, 2023).

Barriers to Urban Food Production

When thinking about increasing the scale of urban agriculture, it is essential to consider the risk of shifting air pollution damages closer to population centers. In the United States, an estimated 17,900 air-quality related deaths annually are attributable to food production (Domingo *et al.*, 2021). 80% of these deaths are attributable to animal products, including both animal feed and the direct production of animals (Domingo *et al.*, 2021). The main contributor to these deaths is ammonia emissions, related to management of manure and nitrogen fertilizer use (Domingo *et al.*, 2021). Urban agriculture typically occurs on a small scale and uses non-conventional farming methods, potentially avoiding the use of animals, field burning, fuel combustion by large farm equipment, and other practices associated with major air pollution impacts. However, it is likely that urban agriculture will involve continued fertilizer use and tillage, which are also important contributors. Small-scale, individual- or community-led urban agriculture may even have the risk of producing more emissions than conventional farming related to excess use of fertilizer and poor fertilizer management due to lack of knowledge of best practices (this same lack of knowledge and over-application issue may also occur with pesticides). However, since high yields are not typically as important for individual- or community-led urban agriculture as for large-scale conventional agriculture, these issues could be reduced through social campaigns promoting reduced fertilizer and pesticide use. Where air pollution damage occurs relative to the source is a complex issue, involving weather patterns, terrain, and other factors, but it is important to consider that shifting a source of air pollution into urban areas may also shift the damage closer to large populations, potentially increasing overall harm.

Soils located near frequent vehicle traffic or on industrial sites may contain significant levels of pollutants, including heavy metals. Plants can be so efficient at removing pollutants from soils that there is an entire field - phytoremediation - devoted to it. Unfortunately, plants intended for human consumption can also uptake pollutants efficiently, passing those potentially harmful compounds onto the people that consume them. A study of corn produced near roads in Greece found that the soil and corn plants grown near roads had elevated levels of various metals, including lead (Kalavrouziotis *et al.*, 2007). Another study constructed pollution maps of platinum group elements (Pt, Pd, and Rh) and polycyclic aromatic carbons emitted by vehicles in rye grown at various distances from a frequently used road (Dan-Badjo *et al.*, 2008). They found the highest levels of pollutants in plants grown within 10 m of the road, with the levels of each pollutant declining by 39-60% by 50 m from the road (Dan-Badjo *et al.*, 2008). A similar study of squash grown near roads in Bangladesh found that lead and nickel concentrations were highest in vegetables grown closest to the road (Naser *et al.*, 2012). Though contamination of the environment with lead has decreased since the removal or reduced use of lead-containing gasoline and paints, lead is very persistent in soils (Rosen, 2002). The highest levels of lead have been detected in soils near building foundations and busy roads (Rosen, 2002). Plants do not generally uptake large amounts of lead, though in soils containing high amounts of lead, they can uptake some (Rosen, 2002). The highest levels of lead are typically found in plant leaves and roots, affecting the safety of leaf and root crops such as lettuce, herbs, carrots, and radishes (Rosen, 2002). Many of the areas suggested in this analysis as potential sites for fruit and vegetable production are located very close to busy roads and potentially near old buildings or industrial sites where soils may be contaminated with lead and other pollutants. Remediating contaminated soil or bringing in uncontaminated soil from another site may be options for still growing food in these locations, however, the continued pollution by cars and industry should be considered.

Conclusion

Current production of fruits and vegetables in Ramsey County, Minnesota is small, but there is substantial potential to increase production through shifting agricultural land use and establishing growing spaces on rooftops and parking lots. Even with all four potential production areas analyzed in this study, 90% of Ramsey County's fruit and vegetable needs would still need to be met by production outside of the county. This highlights urban populations' continued reliance on rural agriculture to meet their nutritional and caloric needs. While urban agriculture offers many benefits and may be an important part of building a more sustainable food system, it is unlikely to produce anything near the food needs of an urban population, even when only considering fruits and vegetables. However, given the environmental strains on rural agricultural systems, it may become necessary to produce a larger portion of food in urban areas, which will require innovative and creative methods of growing food beyond those considered in this study, such as indoor gardens, minimally-protected winter food production, and taking advantage of microclimates to grow a greater diversity of crops. While a completely local diet may not be a desirable or practical target for urban populations, a partially local diet is worth striving for. Producing and consuming local food during the growing season may increase people's connection to food systems, strengthen local economies, and reduce food waste. The small current and potential scale of urban agriculture does not mean it is not worth pursuing, but does mean that research and policy efforts to improve sustainability of the food system as a whole may be able to create more impact by focusing on improving rural agriculture rather than expanding urban agriculture. After all, rural agriculture is the reason cities were able to develop in the first place, and its continued success is the reason they will continue to exist in the future. While urban areas may want to expand their food production systems for the many social, economic, and environmental benefits it offers, the greatest environmental benefits of sustainable food systems will be the result of the changes that are adopted by rural food producers.

Appendix

Table A1. Fruit tree production in Ramsey County in 2017.

Fruit Trees (18 acres total)	Production Area (acres) (Bearing and Non-Bearing)
Apples	15
Apricots	(D)*
Cherries, tart	(D)*
Grapes	(D)*
Plums	2
Remaining Acres	**1**

* (D) indicates the value was not disclosed by the USDA due to the small number of producers.

Table A2. Vegetable, melon, and potato production in Ramsey County in 2017.

Vegetables, Melons, and Potatoes (86 Acres Total)	Production Area (acres)	Vegetables, Melons, and Potatoes	Production Area (acres)
Beans, snap	4	Peas, Chinese	1
Beets	1	Peas, green	(D)*
Broccoli	2	Peppers, bell	2
Cabbage	4	Peppers, chile	3
Carrots	2	Potatoes	8
Cauliflower	2	Pumpkins	2
Cucumbers	3	Radishes	2
Eggplant	(D)*	Rhubarb	1
Garlic	2	Spinach	1
Herbs, fresh cut	1	Squash, summer	3
Kale	2	Squash, winter	9

Lettuce	3	Sweet corn	13
Melons, watermelon	2	Sweet potatoes	1
Okra	(D)*	Tomatoes, in the open	2
Onions, dry	2	Turnip greens	(D)*
Onions, green	1	Turnips	1
Parsley	1	Other Vegetables	5
Remaining Acres		**0**	

* (D) indicates the value was not disclosed by the USDA due to the small number of producers.

Table A3. Greenhouse vegetable production in Ramsey County in 2017.

Greenhouse Vegetables (73,657 ft^2)	Production Area (ft^2)
Tomatoes	57,735
Other Vegetables and Herbs	15,922
Remaining Square Feet	**0**

Table A4. Estimated average yield data for each crop.

Crop	Average Yield (lb/acre)	Source	Years Included	Geographic Level	Notes
Apples	8,472	NASS Quick Stats	2007-2017	State (Minnesota)	
Apricots	10,543	NASS Quick Stats	2007-2021	National	
Beans, snap	9,167	NASS Quick Stats	2016-2021	State (Minnesota)	
Beets	30,153	NASS Quick	1998-2000	State	

		Stats		(Wisconsin)	
Berries (other)	29,013	NASS Quick Stats	1998-2021	National	No “other berries” yield data available. Used average yields of strawberries, blackberries, boysenberries, blueberries (wild and cultivated), and raspberries.
Broccoli	15,221	NASS Quick Stats	1998-2021	National	
Cabbage	48,800	NASS Quick Stats	2016-2021	National	Yield data was not available separately for head cabbage and Chinese cabbage.
Carrots	50,083	NASS Quick Stats	2016-2021	State (Wisconsin)	
Cauliflower	14,000	NASS Quick Stats	1998-1999	State (Michigan)	
Cherries, tart	5,459	NASS Quick Stats	2007-2021	State (Wisconsin)	
Cucumbers	12,500	NASS Quick Stats	2016-2021	State (Minnesota)	
Garlic	16,388	NASS Quick Stats	1998-2021	National	
Grapes	11,189	NASS Quick Stats	2007-2017	State (Michigan)	
Herbs, fresh cut	4,000	New England Vegetable Management Guide	N/A	N/A	Yield data on basil was used to estimate total herb yields since it is a major herb crop in Minnesota.
Kale	18,450	NASS Quick Stats	2000-2001	National	

Lettuce	29,146	NASS Quick Stats	2016-2021	National	
Melons, watermelon	35,958	NASS Quick Stats	2016-2021	National	
Onions, dry	43,000	NASS Quick Stats	2015	State (Wisconsin)	
Onions, green	18,000	New England Vegetable Production Guide	N/A	N/A	
Parsley	16,000	New England Vegetable Production Guide	N/A	N/A	
Peas, Chinese (sugar and snow)	6,000	New England Vegetable Production Guide	N/A	N/A	
Peas, green	3,308	NASS Quick Stats	2016-2021	State (Minnesota)	
Peppers, bell	24,833	NASS Quick Stats	1998-2021	State (Michigan)	
Peppers, chile	17,783	NASS Quick Stats	2000-2021	National	
Plums	12,644	NASS Quick Stats	2007-2021	National	
Potatoes	39,660	NASS Quick Stats	1998-2022	State (Minnesota)	
Pumpkins	16,833	NASS Quick Stats	2016-2018	State (Minnesota)	
Radishes	6,750	NASS Quick Stats	2000-2001	State (Michigan)	
Rhubarb	14,000	New England Vegetable Production	N/A	N/A	

		Guide			
Spinach	13,362	NASS Quick Stats	2016-2021	National	
Squash	20,432	NASS Quick Stats	2000-2021	State (Michigan)	Yield data was not available separately for winter squash and summer squash.
Sweet corn	15,000	NASS Quick Stats	2016-2021	State (Minnesota)	
Sweet potatoes	18,843	NASS Quick Stats	1998-2021	National	
Tomatoes, field	55,500	NASS Quick Stats	2016-2018	State (Michigan)	
Tomatoes, under protection	174,240	New England Vegetable Production Guide	N/A	N/A	
Turnips	24,000	New England Vegetable Production Guide	N/A	N/A	
Other vegetables, field	21,472	Average of all vegetable yields (field)	N/A	N/A	An average of all other vegetable yields available was used.
Other vegetables, greenhouse	17,199	Average of leafy greens yields (field)	N/A	N/A	Used average of the field yields of lettuce, kale, and basil.

Table A5. Average grams per cup of each crop.

Crop	Average Weight Per Volume (g/cup)	Crop	Average Weight Per Volume (g/cup)
Apples	110	Parsley	60

Apricots	165	Peas, Chinese (sugar and snow)	98
Beans, snap	100	Peas, green	145
Beets	136	Peppers, bell	149
Berries (other)[1]	138	Peppers, chile	150
Broccoli	91	Plums	165
Cabbage, Chinese	70	Potatoes	150
Cabbage, head	89	Pumpkins	116
Carrots	128	Radishes	116
Cauliflower	107	Rhubarb	122
Cherries, tart	103	Spinach	30
Cucumbers	104	Squash, summer	130
Garlic	136	Squash, winter	140
Grapes	92	Sweet corn	145
Herbs, fresh cut[2]	6	Sweet potatoes	133
Kale	21	Tomatoes, field	158
Lettuce	36	Tomatoes, under protection	158
Melons, watermelon	152	Turnips	130
Onions, dry	160	Other vegetables, field[3]	109
Onions, green	71	Other vegetables, greenhouse[4]	21

[1]Average of blueberries, blackberries, and raspberries.
[2]Data for basil.
[3]Average of all other vegetables.
[4]Average of lettuce, basil, and kale.

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