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Urban Soil Chemical and Nutrient Management Issues Facing Emerging Small Grower Enterprises in Utah

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URBAN SOIL CHEMICAL AND NUTRIENT MANAGEMENT ISSUES FACING EMERGING SMALL GROWER ENTERPRISES IN UTAH

by

Frank E. Oliver

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Science

Approved:

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UTAH STATE UNIVERSITY
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ABSTRACT

Urban Soil Chemical and Nutrient Management Issues Facing Emerging Small Grower Enterprises In Utah

by

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Utah State University, 2022

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With increases in urban agriculture, knowledge of both soil quality and contamination has become increasingly important. It is also vital that community gardeners and urban farmers maximize their yields and profits, as urban agricultural spaces are often constrained by space. To address these needs, three studies were conducted: 1) an urban soil survey was used to assess soil contamination along the Wasatch front, 2) a soil survey to evaluate macronutrient (Nitrate-Nitrogen, Olsen Phosphorus and Potassium) and salinity levels in urban agriculture throughout Utah and 3) an optimal nitrogen rate was tested for dahlia (*Dahlia pinnata*), a cut flower with large profit potential in limited spaces. Sites along the Wasatch Front were sampled from the fall of 2020 to spring of 2021 and analyzed for trace elements and hydrocarbon contamination, along with macronutrient levels and general soil quality parameters. Mean arsenic, lead, and benzo (A) pyrene, a common hydrocarbon contaminant, concentrations were 11.79 (±1.6), 91.8 (± 20.7), and 0.09 (± 0.04) mg kg^{-1}. The mean lead and benzo (A) pyrene concentrations were below their respective EPA regional screening limits (RSL) of 400 and 0.11 mg kg^{-}

^{1}, while the mean arsenic concentration was well above the EPA RSL of 0.68 mg kg^{-1}. Mean soil test nitrate N and Olsen P and K levels were 42.3 (±7.0), 98.8(± 9.9), and 435 (±43.9) mg kg^{-1}, respectively. All macronutrient levels were above recommended levels, especially phosphorus, which was three times that of the recommended limit. A field trial for dahlia ‘Café au Lait’, a premium high-value crop, was conducted in 2019 – 2021 at the Utah Agricultural Experiment Station Greenville Farm to test five nitrogen fertilizer application rates (0, 56,112, 168, and 225 kg ha^{-1}) on cut flower yield and quality. 2021 was the most significant year, as the first two had mortality problems due to plant virus. Based upon 2021, the 168 kg N ha^{-1} rate appears to be the most efficient option in terms of yield, while no differences in flower quality were overserved. Optimizing management and yield will provide urban farms with a non-edible crop option with soils not suited for food production.

(124 pages)

PUBLIC ABSTRACT

An Urban Soil Survey of the Wasatch Front and the Effects of Varying Nitrogen Rates on Dahlia Production

Frank E. Oliver

Knowledge of both soil quality and contamination has become increasingly important with the growth of urban agriculture in Utah and the United States as whole. Land is also a common limiting factor in urban agriculture, so it is important to maximize yield and net returns. In order to meet these demands, three studies were conducted across key urban agriculture sites along the Wasatch Front: 1) an urban soil survey to assess soil contamination, 2) an urban soil survey to evaluate macronutrient and salinity levels, and 3) a nitrogen fertilizer management trial for dahlia (*Dahlia pinnata*), a cut flower crop with strong profit potential on urban microfarms. Urban agriculture sites included 31 farms and community gardens that were sampled from the fall of 2020 to spring of 2021 and analyzed for trace elements and hydrocarbon contamination, along with macronutrient levels and general soil quality parameters. Five nitrogen rates (0, 56,112, 168, and 224 kg ha^{-1}) were tested in field trial for the yield and quality of dahlia 'Café au Lait' from 2019 to 2021 at the Utah Agricultural Experiment Station Greenville Research Farm. Urban soils were generally below the EPA regional screening limits (RSL) for trace element and hydrocarbon contaminants. However, the mean arsenic concentration was 17 times higher than the EPA RSL of 0.68 ppm, highlighting the need for a localized screening value to inform management practice. The macronutrient levels were above recommended levels across all surveyed sites, with mean soil test phosphorus three times greater than the recommended limit, indicating the need for nutrient management outreach with small, urban farmers and gardeners. Nitrogen management for dahlia was optimized with 168 kg N ha^{-1} application rates, though virus pressure impacted yields during the first two years of the study. Optimizing management and yield can provide urban farms with a high-value, non-edible food crop option on soils not suited for food production. Routine soil nutrient testing along with site screening for soil contamination is vital to maintaining long-term health and sustainability in urban agriculture.

CONTENTS

Page

Abstract iv

Public Abstract v

List of Tables ix

List of Figures x

CHAPTER

I. Literature Review 1
  Introduction 1
  Urban Soil Quality 2
  Urban Soil Fertility for High-value crops: Dahlia 12
  Objectives 16
  Literature Cited 18

II. An Urban Soil Survey of Trace Elements and Organic Contaminants Along the Wasatch Front 25
  Introduction 26
  Materials and Methods 32
  Results 35
  Discussion 37
  Literature Cited 42

III. A Survey of Soil Quality in Urban Agriculture Along the Wasatch Front 57
  Introduction 58
  Materials and Methods 62
  Results 63
  Discussion 65
  Literature Cited 68

IV. The Effects of Varying Nitrogen Rates on Dahlia Yield And Production 75
  Introduction 76
  Materials and Methods 81
  Results 86
  Discussion 89
  Literature Cited 93

V. Conclusion 99

Appendices 102
  Appendix A...103
  Appendix B...112

LIST OF TABLES

Page

Table 2.1 Federal and state soil screening levels for lead (Pb), arsenic (As), and benzo (A) pyrene B(A)P 48

Table 2.2 Summary of the urban soil sampling sites along the Wasatch Front 49

Table 2.3 Class divisions of average Annual Daily Traffic (AADT) and in vehicles per day and road proximity in m 50

Table 2.4 Survey site number and corresponding traffic information, including Annual Daily Traffic (AADT), proximity to nearest road, and dual traffic score, a product of the AADT and road proximity rankings 51

Table 2.5 Arsenic, lead, and benzo (A) pyrene concentrations in mg kg^{-1} for each survey site 52

Table 3.1 Summary of soil sampling sites along the Wasatch front by crop, soil type, and the size of the site 71

Table 3.2 Concentrations of NO_3-N and Olsen P and K along with total carbon, salinity, and pH for each soil sampling location 72

Table 4.1 Mean (±SD) macronutrient (Nitrate-N, Olsen P and K), salinity, and pH values for the UAES Greenville farm and grower participant studies 96

LIST OF FIGURES

Page

Figure 2.1 Mapped overview of measured contaminant levels relative to EPA NPL sites with 5 km buffers around each NPL site 53

Figure 2.2 Mapped overview of geoaccumulation index value relative to EPA NPL sites with 5 km buffers around each NPL site 54

Figure 2.3 Total soil concentrations of arsenic (As, top), lead (Pb, middle), and benzo (A) pyrene (B(A)P), bottom) in mg kg^{-1} for each site and its distance to each EPA NPL smelting activity site in km. 55

Figure 3.1 Map of primary crop type for each sampling site with county boundaries. ...73

Figure 3.2 Primary macronutrient levels (Nitrate-N, Olsen P and K) in mg kg^{-1} plotted by primary crop type...74

Figure 4.1 Mean (±SD) yield as total stems per plant by nitrogen (N) fertilizer rate for the UAES Greenville farm study across 2019, 2020, and 2021 96

Figure 4.2 Total cumulative yield by nitrogen rate for the UAES Greenville farm study across 2019, 2020, and 2021. 97

CHAPTER 1

LITERATURE REVIEW

Introduction

In the past 30 years, the number of urban farms grew by 30% across the US (Siegner et al., 2018), and the 2017 USDA Agricultural Census found that urban farms now make up close to 15% of all US farms (Rangarajan et al., 2019.) In Utah, the mean farm size has decreased by almost 80 hectares since 1997, while the total number of farms increased from approximately 13,000 farms in 1990 to 16,600 farms in 2010 (Utah Agricultural Sustainability Task Force, 2011). There has also been a demographic shift to urban areas in Utah. In 1900, 40% of the population lived in urban areas, and by 2010, this value increased to 90% (Utah Agriculture Sustainability Task Force, 2012). These statistics show that while the number of larger, more traditional farms have decreased, the total number of farms has increased, which could potentially be attributed to the growth of urban farms and community gardens as a result of population growth in urban areas.

The growth of community gardens has been substantial over the last two decades. Approximately 6,000 community gardens were established across 38 US cities by 1996, and by 2010, the number of community gardens in the US was estimated to be nearly 10,000 (Lee, 2010). A five-year study from the National Gardening Association also found the number of households involved in some form of food gardening increased from 36 million in 2008 to 42 million in 2013, which represents approximately 35% of all US households (National Gardening Association, 2014). In Utah, there are an estimated 39

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community gardens along the Wasatch Front. Starting a community garden requires interest from a local community, with a minimum of ten families usually required to start and maintain a community garden (Surls et al., 2001). Establishing a garden includes finding land and contacting the landowner, securing water, testing the soil, and forming a lease agreement. A review of community garden literature found that among 87 academic papers, 19% reported access to land as the most common challenge among community gardens, while soil contamination, safety, water, and funding were also highlighted (Guitart et al., 2012).

Urban Soil Quality

With the growth of farms and gardens on urban land, soil quality is becoming increasingly important, particularly as underutilized, vacant spaces are considered for food production (Kaiser et al., 2015). These urban areas are often at a higher risk for soil contamination compared to rural areas, as urban areas are more densely populated, industrialized, and heavily trafficked by automobiles, which can contribute to soil contamination (EPA, 2011). Urban soils are also often unmapped, unclassified, or have different properties from original NRCS soil survey descriptions (NRCS, 2021). In Salt Lake County specifically, 5,697 hectares of land, or 3.4% of the total land in the county, is classified by the NRCS as urban land (NRCS, 2021). This lack of information, paired with discrepancies in background knowledge and greater risk of contamination for urban soils, create challenges for establishment of urban gardens and farms, particularly with site selection (EPA, 2011).

Nutrient management practices in urban farms and community gardens differ from those of conventional, large-scale agricultural operations, and has been studied in the eastern U.S. and Europe. Over fertilization of nitrogen (N) and phosphorus (P) were examined among urban farmers in the Twin Cities metropolitan area in Minnesota, where the median application rates were 1400 kg N ha^{-1} and 300 kg P ha^{-1} (Small et al., 2019). As a result, soil test P (from the Bray-P 1 Method) was 80 mg kg^{-1}, which was significantly greater than optimal Bray-P levels of 31-45 mg kg^{-1} for garden soils (Small et al., 2019; Laboski and Peters, 2012). In Chicago, Illinois, 21 sites were sampled, and macronutrient concentrations were found to be elevated, with median P and potassium (K) levels ranging from 94.3 to 225.4 mg kg^{-1} and 345 to 936 mg kg^{-1}, respectively, and recommended soil test K values ranging from 141-200 mg kg^{-1} (Ugarte and Taylor, 2020; Laboski and Peters, 2012). In the Netherlands, the form and number of amendments applied were compared between urban and conventional agriculture. The mean urban farm application rates were 789 kg N ha^{-1} yr^{-1} and 267 kg P_2O_5 ha^{-1} yr^{-1}, while standard application guidelines for the country were 209 kg N ha^{-1} yr^{-1} on clay soils and 75 kg P_2O_5 ha^{-1} yr^{-1} on soils with low phosphorus contents (Wielemaker et al., 2018). These case studies show that overapplication of nutrients is often a common occurrence in urban agriculture, which presents challenges for on-farm nutrient losses to runoff, potential for elevated soil salinity, and an inefficient use of financial resources.

Primary macronutrients are often applied via manure or compost in urban settings, which can lead to accumulation of P and K (Wielemaker et al., 2018). Moreover, use of manure-based composts can elevate soil salinity, increasing crop stress (Gondek et al., 2020). In a comparison of excessive application of organic and chemical fertilizer across different P fractions in Shanghai, China, and organic fertilizers increased overall soil test P levels by 366 mg kg^{-1}, while chemical fertilizers resulted in a soil test P concentration of 287 mg kg^{-1} (Song et al., 2017). In Saint Paul, Minnesota, manure-based composts were compared to municipal composts, and manure-based composts were found to leach significantly more P, with a maximum leaching value of 0.95 g P 0.3 m^{-2} compared to 0.2 g P 0.3 m^{-2} for municipal sources. Compost application rates in this study were 36 times greater than the crop demand for P, resulting in increased input costs and runoff risk (Small et al., 2018). In Utah and other arid to semi-arid environments, overuse of compost increases risk of elevated salinity, particularly with manure-based sources, which average 1.5 dS m^{-1} greater salinity than municipal and plant-based sources (Stock et al., 2019). Over-application of compost on small farms in drier climates presents a challenge to maintaining soil salinity levels less than 2 dS m^{-1} for most horticultural crops (Stock et al., 2020).

In addition to soil fertility and salinity, urban soil contamination must also be considered for community gardens and farms, particularly lead, arsenic, and hydrocarbons (EPA,2011). Exposure to contaminants in soils includes inhalation, ingestion, and dermal contact (EPA, 2020). Evaluating contamination is often based on both the soil test value and the natural level at which contaminants regionally occur in the soil. Soil test values are compared to regional screening levels (RSLs) developed by the U.S. EPA that serve as baselines for determining whether concentrations are elevated and hazardous. The EPA currently bases RSLs on a cancer risk assessment of 10^{-6}, which translates to a risk level where one in a million people will develop cancer over a lifetime exposure, and two methods of evaluating contaminant cancer risks are oral slope factors

(SFO) and inhalation unit risks (IUR). The SFO estimates the likelihood of developing cancer with lifetime oral exposure to a contaminant and is expressed in mg kg^{-1} per day while the IUR evaluates the probability of developing cancer from constant exposure to a contaminant in the air, expressed in μg m^{-3} (EPA, 2020). While there are other methods of evaluating soil contamination risk, cancer-based approaches are most commonly used, and developed from SFO and IUR methods that evaluate lifetime risk.

Lead, a common contaminant in urban soils, is attributed to leaded gasoline, lead paint, lead-arsenate pesticides, or point-source emitters, such as smelters and mine tailings (EPA, 1998). The U.S. EPA RSL for total soil lead is 400 mg kg^{-1} across the US, and it is based on health effects linked to exposure that include adverse brain development in children, nerve disorders, and high blood pressure (EPA, 2020). The SFO and IUR for lead are 0.0085 mg kg^{-1} per day and $1.2 * 10^{-5}$ μg m^{-3} (California Office of Environmental Health Hazard Assessment, 2011). In soils, lead is highly immobile, and can persist in the soil for up to 5,000 years (Saxena et al., 1999). The mean background lead concentration for the conterminous United States is 16 ppm, though variations may occur across the country due to climactic and geologic factors. Specifically, states west of the 96th meridian averaged background concentrations of 17 ppm and ranged from 10 to 700 ppm, while those east averaged 14 ppm and ranged <10 to 300 ppm (Shacklette and Boerngen, 1984).

Urban exposure to lead is a common concern, as cities can undergo redevelopment that masks former industrial areas, and they have greater traffic densities compared to more rural and less disturbed areas. In New York City, the mean concentration of lead in parks and other recreational areas with historic industrial use was

320 mg kg^{-1}, while areas without prior industrial use averaged 105 mg kg^{-1} (Pavilonis et. al, 2020). In a New York City community garden that was adjacent to two moderately trafficked roads, the mean lead concentration was 816 mg kg^{-1} (Paltseva, 2019), while soil within one mile of Interstate 880 in California averaged was 568 mg kg^{-1} (Teichman et al., 1993), and along Interstate-75 in Ohio averaged 410 mg kg^{-1} (Turer et al., 2001). These studies highlight the degree to which lead can be elevated in urban environments, and areas that are considered uncontaminated can have levels that are significantly elevated compared to natural background levels.

Point source emitters, such as smelters and mine tailings, are also common sources of contamination in industrial cities. In Philadelphia, Pennsylvania, the mean lead concentration for samples taken in areas with a history of industrial smelting activity was $2.12*10^3$ mg kg^{-1}, while the mean concentration in residential areas with no industrial history was 261 mg kg^{-1} (Lusby et. al, 2015.) A secondary lead smelter in Ontario, Canada was sampled at distances ranging from 15-180 m, while a control sample was measured 1000 m away. Lead concentrations near the smelter ranged from 3,564 to 28,000 mg kg^{-1} and decreased with increasing distance, while the control was 703 mg kg^{-1} (Bisessar, 1982). In Poland, four sites located within a distance range of 1-6 km of a former copper smelter were analyzed for trace element concentrations, and soils ranged 65-130 mg kg^{-1}, with the lowest value occurring at the greatest distance (Kabala and Singh, 2001). Midvale, Utah, has a history of industrial activity, including a smelter that was in operation until 1958 and a mill that produced copper, zinc, and lead and was in operation until 1971. Among 112 soil samples that were collected within the neighborhood of Midvale, 79 were classified as an intervention group, with lead and arsenic levels ranging 466 to 631 mg kg^{-1} and 44 to 56 mg kg^{-1}(Lanphear, 2003). While lead concentrations decrease with distance from point sources, elevated levels exist up to 6 km away, adding risk for potential exposure as sites are redeveloped for urban agriculture.

The distance between a site and potential contaminant source is equally as important as the source type, and buffer threshold distances have ranged throughout population analyses. The EPA established buffer distances of 1.6 and 4.8 km to quantify the population of Americans that live near superfund sites, and they found that approximately 6% of the total US population lives within 1.6 km of a superfund while 22% of the total US population lives within 4.8 km of a superfund site (EPA, 2020). When examining the proximity of superfund sites to juvenile detention centers in the Western US, researchers used buffer distances of 1.6, 2.9, 4.8, and 8.0 km (Ashby et al., 2020.) A 2.4 km buffer was used in a study examining the relationship between superfund proximity and income (Downey and Crowder, 2011), and a 4.0 km buffer was used in a study examining hazardous waste sites and their distance to communities largely made up by people of color (Anderton et al., 1994).

Lead arsenate ($PbHAsO_4$), a pesticide formerly applied to orchards, is a common source of both lead and arsenic contamination and has chemical composition that allows for elevated levels to persist long after the pesticides were last applied (Codling et. al, 2015). Lead arsenate was first introduced in the 1890s and was heavily used until the 1950s, when other options, such as DDT, became more available and widely used (Wolz et. all, 2003). Though soils with former orchards had elevated levels compared to sites without, currently no studies indicate lead levels were greater the RSLs. For example, in

Washington, soils on or within 60 m of historical orchards had median lead and arsenic concentrations of 65.9 mg kg^{-1} and 7.0 mg kg^{-1}, while those beyond 60 m had median concentrations of 7.8 and 2.8 mg kg^{-1} (Wolz et. all, 2003). In North Carolina, a former orchard with known lead arsenate use was repurposed into a residential community in the 1990s. The mean lead concentrations ranged 480 to 930 mg kg^{-1}, while the mean arsenic ranged 91 - 240 mg kg^{-1}, and variability was attributed to soil mixing from agricultural activity (Embrick et al., 2005). In soils contaminated by lead arsenate pesticides, arsenic is primarily found in the As(V) redox state, which is less mobile and toxic than the As(III) redox state. While the mobility of As(V) is lower, the use of phosphate fertilizers on lead arsenate contaminated soils has been shown to increase arsenic mobility, which could lead to higher crop uptakes or the leaching of arsenic into water tables (Gamble et al., 2018). Moreover, moderating organic matter management may also help regulate the bioavailability of arsenic, as higher organic matter applications have been shown to increase arsenic bioavailability (Clarke et al., 2015).

Other common sources of arsenic in soil include chromated copper arsenate (CCA) treated wood, sewage sludge, and point source emitters (Belluck et al., 2003). While arsenic is chemically a metalloid, it is often treated as a heavy metal for the purposes of evaluating environmental contamination and health risks (EPA, 1998). In the soil, arsenic is immobile and has the potential to persist for hundreds to thousands of years, with lifespan estimates up to 9,000 years (Washington State Department of Health, 1999). The mean arsenic concentration for the conterminous US is 5.2 mg kg^{-1} (Shacklette and Boerngen, 1984). Background concentrations are greater in the western US (west of the 96th meridian), which averages 5.5 mg kg^{-1} and ranges <0.1 to 97 mg kg^{-}

^{1}, while the eastern US averages 4.8 mg kg^{-1} and ranges <0.1 to 73 mg kg^{-1} (Shacklette and Boerngen, 1984). Long term arsenic exposure has been linked to lung, bladder, and skin cancer, along with increased risk of diabetes and heart disease (Washington State Department of Ecology, 2020). As with other contaminants, ingestion and inhalation are the most common means of human exposure, and the SFO and IUR are 1.5 mg kg^{-1} per day and 0.0045 μg m^{-3} (EPA, 2020).

While state screening levels for lead are generally consistent with the EPA RSLs, guidance for arsenic varies widely by region or state. The EPA RSL for arsenic, which is based upon a cancer risk of 10^{-6}, or a risk that one person out of a million will develop cancer over lifetime exposure, is 0.68 mg kg^{-1} (EPA, 2021), which is significantly lower than the mean national background concentrations of uncontaminated soils. There are 13 states that follow this risk model or directly defer to the EPA guidelines (Teaf et al., 2010). However, discrepancies exist as other states base state guidance levels upon natural background levels or different risk models. As a result, state screening levels range from 0.039 to 40 mg kg^{-1} across the US (Teaf et al., 2010) (Table 2.1).

Though the lumber industry and the EPA agreed to discontinue CCA-treated wood for residential structures in 2003, CCA leaching from treated lumber, as well as leaks and spills at treatment facilities, persist as common sources of arsenic contamination (Zagury et al., 2003). In Canada, arsenic concentrations from soil samples taken adjacent to CCA-treated poles ranged 153-410 mg kg^{-1} at the ground line and 17-54 mg kg^{-1} at a 1 m depth. Surface samples of arsenic also decreased with distance to the poles, as samples taken at a 0 m depth 0.5 m away from the pole ranged from 5.3 to 15 mg kg^{-1} (Zagury et al., 2003). Under nine residential decks in Florida, the surface soil (upper 0.025 m), eight were confirmed to be treated with CCA and ranged in total arsenic from 1.18 to 217 mg kg^{-1} with a mean of 28.5 mg kg^{-1}, while the mean background level was 1.36 mg kg^{-1} (Townsend et al., 2003). Soil samples collected from the upper 5 cm under seven decks in Connecticut, had a median arsenic concentration of 76 mg kg^{-1} and a range of 3-350 mg kg^{-1}. Control samples, collected 5 km away from decks, were significantly lower in arsenic, with a mean concentration of 3.7 mg kg^{-1} and a range of 1.3-8.3 mg kg^{-1} (Stilwell and Gorney, 1997). CCA-treated wood has the potential as a major risk factor for arsenic contamination, particularly in near-surface soils, however, areas of concern will often be directly below or adjacent to the source of leaching.

Point source emitters are another significant source of soil arsenic, with common examples including mine tailings and emissions from industrial sources, such as smelters and factories. Arsenic concentrations for sites with mine tailings in Canada ranged from <0.07 mg kg^{-1} to 2200 mg kg^{-1}, depending on mine type, with copper, copper-zinc, and lead-zinc mine tailings resulting in the greatest arsenic concentrations (Wang and Mulligan, 2006). In Tacoma, Washington, soil sampled within 5 km of a smelter had a maximum arsenic concentration of 380 mg kg^{-1} (Crecelius et al., 1974). In Salt Lake County, Utah, arsenic levels ranged from 5-540 mg kg^{-1} at the Kennecott Garfield copper smelter, which was estimated to have emitted arsenic and other pollutants from 1906 to 1978, with the highest concentrations occurring within a 3 km distance of the smelter (Ball et al., 1983). As with lead, industrial point source emitters have the potential to significantly contaminate on-site soil and elevate broader areas above natural background levels.

Hydrocarbon contaminants include polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), and polychlorinated biphenyls (PCBs) (Srivastava et al, 2019), and can occur naturally or through anthropogenic enrichment. Natural sources include forest fires, diffusion of hydrocarbons from petroleum-rich rock, and biosynthesis from organisms, while anthropogenic contamination often results from the burning of fossil fuels or other organic compounds, or through the spillage and/or leakage of petroleum compounds (Srivastava et al, 2019). The EPA RSL for benzo (A) pyrene, a common hydrocarbon contaminant, is 0.11 mg kg^{-1}, and it has an SFO of 1 mg kg^{-1} per day and an IUR of $6 * 10^{-4}$ μg $(m^3)^{-1}$ (EPA, 2020). Exposure to hydrocarbons has been linked to increased risks for cancer, liver and kidney damage, jaundice, and cataracts (Illinois Department of Public Health, 2020), and the lifespan and mobility of hydrocarbons in the soil is largely based on the molecular weight of the compound. At a 0-15 cm depth in a Miami, Florida, soil, the concentration of low-molecular-weight hydrocarbons (i.e., with two to three benzene rings) ranged from 0.47–0.76 mg kg^{-1}, while the range for higher-molecular-weight hydrocarbons (i.e., with four or more benzene rings) was 1.04–1.60 mg kg^{-1} (Banger et al., 2010). Examples of low molecular weight PAHs include naphthalene and anthracene, while benzo (A) pyrene and chrysene are two examples of high molecular weight PAHs. The greater concentrations of high molecular weight compounds indicate that the source was likely pyrogenic, while sites with greater presence of low molecular weight compounds are often attributed to the formation of petroleum sources (Wolska et al., 2012).

The burning of fuel and the leakage of petroleum chemicals from automobiles also contribute to hydrocarbon contamination in soil (Srivastava et al., 2019.) In

Puducherry, India, the concentration of hydrocarbons in soil adjacent to mechanic workshops along a major highway ranged from 90.72-121.79 mg kg^{-1}, while samples taken from agricultural fields located alongside the highways ranged from 44.94 to 83.4 mg kg^{-1} (Khan and Kathi, 2014). Soil samples were taken near a road in Brisbane, Australia at distances ranging from 0.5-15 m, and the mean hydrocarbon concentration at 0.5 m was 3.35 mg kg^{-1}. In particular, Benzo (A) pyrene decreased in concentration with increasing distance from the road, as the mean concentration was 0.36 mg kg^{-1} at 0.5 m and 0.08 mg kg^{-1} at 15 m (Yang et al., 1991). In Delhi, India, industrial and roadside soil samples had mean benzo (A) pyrene concentrations of 0.56 and 0.37 mg kg^{-1}, while samples taken from residential and agricultural resulted in means of 0.11 and 0.06 mg kg^{-1} (Singh et al., 2012). A pasture located adjacent to a French highway with a traffic value of 70,000 vehicles per day was sampled at distances of 10, 50, and 150 m. The mean concentration of total PAHs was 2.6 mg kg^{-1} at 10 m and decreased to 1.1 mg kg^{-1} at 150 m, while Benzo (A) pyrene had a mean concentration of 0.2 mg kg^{-1} at 10 m, 0.07 mg kg^{-1} at 50 m, and 0.05 mg kg^{-1} at 150 m (Crépineau et al., 2003). Hydrocarbon contamination significantly decreases with distance from roadways, but hydrocarbon levels remain elevated at distance compared to sites that are not adjacent to roadways or other sources of automobile pollution.

Urban Soil Fertility for High-value crops: Dahlia

When sites have contaminated soils, growing nonedible crops, such as cut flowers, reduces human health risk by reducing exposure to soil contaminants, such as through ingestion pathways (EPA, 2020). Cut flowers also offer a premium profit potential with minimal land requirements for urban agriculture, with net returns of flowers such as snapdragons and peonies averaging \$25.00 per m^2 (Lewis et al., 2021). Moreover, the increasing demand for cut flowers has led to a rapid growth of flower farms across the US. According to the 2015 Floriculture Crops Summary, the number of growers increased by 5% in top producing states from 2014 to 2015, and the domestic cut flower market was valued at \$374 million wholesale (USDA-NASS, 2016). Membership in the Association of Specialty Cut Flower Growers (ASCFG) also reflects the recent growth of farms at the national level, as membership has increased from 1,401 to 2,553 in the last two years (personal communication, Judy Laushman, 29 June 2021). In the U.S. Mountain West, the number of cut flower micro farms has increased, particularly in Utah, where 105 farms established in the last five years, at a rate of approximately 30 new cut flower farms per year (Stock, unpublished data). The Utah Cut Flower Farm Association (UCFFA) established in 2019 and has grown to 125 members (UCFFA, 2021). Local growers have targeted specialty cut flowers, prioritizing production of flowers that do not transport well and have a relatively short vase life for direct-to-consumer sales through farmers markets and community-supported agriculture (CSAs).

With the current increases in urban farming and cut flower production, particularly in less traditional regions for production such as the US Intermountain West, it is important that growers have access to current research and locally adapted production recommendations. In 2020, 85% of surveyed cut flower growers in Utah identified a lack of regional guidelines as the main challenge for cut flower farming in the state (Survey of cut flower growers by M.N. Stock, 5 March 2020), as the climate, soils, and water quality vary from conditions in the traditional coastal hubs. Dahlias (*Dahlia sp.)* are particularly challenging to produce, yet are widely grown in Utah, with 72% of farms relying on dahlias as a primary summer to fall flower crop (Stock, 2020). Dahlias ship poorly and have strong consumer demand, have a relatively short storage and vase life, thus high quality, local stems command premium market pricing, with wholesale receipts averaging $4 to $5 per stem (Stock, 2020).

Dahlias are tuberous, herbaceous perennial plants within the Asteraceae family and are native to Mexico (Schie, 2013). In temperate climates (e.g., USDA Hardiness Zones 7 and below), dahlias are grown as annuals during the frost-free growing season, typically from late May to early October in Northern Utah (Utah Climate Center, 2021). Though *Dahlia* is a diverse genus with 42 recognized species (American Dahlia Society, 2021), *D. pinnata* is primarily used for cut flower production, with common bloom types including dinnerplate, cactus, ball, and pompom. Dinnerplate varieties produce the largest dahlia blooms, with flower diameter reaching 0.3 m and plants reaching 2.4 m in height (Chandraju et al., 2013). Though dinnerplate varieties are highly marketable and bloom continuously until first frost, bloom initiates later in the season (e.g., August to September) compared to other bloom types, resulting in challenges with yield (Mariña, 2015).

When evaluating bloom timing, nutrient management, particularly higher nitrogen (N) rates, may lengthen the period to first bloom due to increased vegetative growth, which can be measured by factors such as plant height and leaves per plant. The American Dahlia Society (2001) recommends 195 kg N ha^{-1} and states growers commonly apply 2-3 times more fertilizer than needed, which can reduce yield by 25 %. Research-based recommendations vary, with most ranging from 50 to 100 kg N ha^{-1} (Gani et al, 2007; Sheergojri et al., 2013; Barik, 2017; Prasad et al, 2019), though none have been conducted in regions with conditions similar to the U.S. Mountain West. In assessing bloom timing in India, an 80 kg N ha^{-1} application resulted in first bud appearance occurring at 73 days, while first bud in the control (0 kg N ha^{-1}) occurred at 69 days, though comparing one rate to a zero-application rate control may introduce confounding factors. In the same study, the 80 kg N ha^{-1} rate resulted in 37 leaves per plant and a mean plant height of 0.46 m compared to 28 leaves per plant and 0.36 m plant height in the unfertilized control (Gani et al., 2007). Another greenhouse study tested N rates up to 100 kg N ha^{-1} and found the mean plant height was 0.62 m at 50 kg N ha^{-1} rates, 0.71 m at 76 kg N ha^{-1} rates, and 0.71 m at 100 kg N ha^{-1} rates, indicating no significant difference in vegetative growth between 76 and 100 kg N ha-1 rates (Sheergojri et al., 2013). In evaluating nutrient application rates with regards to bloom timing, greater application rates did not delay timing to bud appearance, hence harvest. Applying 50 N, 60 P_2O_5, and 50 K_2O kg ha^{-1} and 50 kg ha^{-1} vermicompost, which can range from 1.5 to 1.8% N, 1.3 to 1.6% P, and 0.8 to 15.8% K, required 51 days before the first bloom appeared, while the control (0 kg N ha^{-1}) took 60 days to produce the first bloom (Barik, 2017; Mistry et al., 2015). In a similar trial that evaluated a 75 N 90 P_2O_5 75 K_2O kg ha^{-1} and 1.25 T ha^{-1} vermicompost to an unfertilized or amended control, the timing to first flower opening was 57 days in the fertilized treatment, while the control required 74 (Prasad et. al, 2018). As the tested N rates remained relatively low across studies, have largely only been compared to unfertilized controls, and most trials occurred in greenhouse systems, more research is needed to determine the impact of greater rates with timing and growth, as well as interpret guidelines for field-based farm systems.

Along with total yield, considering stem lengths and bloom size are important in establishing recommendations, as these are graded for wholesale and retail pricing. In assessing yield in greenhouse production, 80 kg N ha^{-1} produced a mean of 6.55 flowers per plant with a mean bloom diameter of 186 mm, compared to 2.55 flowers per plant at a mean bloom diameter of 141 mm in the unfertilized control (Gani et al., 2007). An application of 75 N 90 P_2O_5 75 K_2O kg ha^{-1} and vermicompost at 1.25 t ha^{-}1 produced 9.9 flowers per plant with mean flower diameters of 220 mm, while the 0 N control produced 6.6 flowers per plant with a mean flower diameter of 172 mm (Prasad et. al, 2018). A similar study determined applying 50 N 60 P_2O_5 50 K_2Okg ha^{-1} and 50 kg ha^{-1} vermicompost application averaged 10.1 flowers per plant with a mean stem length and bloom diameter of 250 mm and 251 mm, respectively, while the unfertilized control produced 5.3 flowers per plant, a mean stem length of 121 mm, and a bloom diameter of 185 cm (Barik, 2017). While dahlias have the potential to command premium pricing for urban farms, regional N rate recommendations are needed, particularly in the U.S. Mountain West, where overapplication of fertilizers and amendments may reduce yield, increase input costs, and elevate soil salinity.

Objectives

Urban Soil Survey: Contaminants and Quality

The objective of the study was to collaborate with key urban farm and garden leaders to select priority sites for an urban soil survey that examines soil quality and contamination risk by assessing: primary macronutrient levels, organic carbon, salinity, and pH, texture, trace elements (i.e. lead and arsenic), and hydrocarbons (petroleum hydrocarbons, polycyclic aromatic hydrocarbons, and volatile organic compounds). Soil survey results will be used to develop an urban soil test package that bundles tests of key soil properties for production and screens common urban contaminants. A USU Extension fact sheet will be developed that summarizes survey results and provides interpretation of the urban soil test package results.

Varying Nitrogen Rates on Dahlia Production

The goal of this study was to evaluate the growth, yield, bloom timing, and quality of *Dahlia* ‘Café au Lait’ in response to five nitrogen application rates (0, 56, 1112, 168, 224 N kg ha^{-1}) across a three-year field trial. Dahlia production timing, yield, and profitability of six grower collaborators across the Wasatch Front was also evaluated with the field trial. Through this research, we aimed to develop regional nitrogen application rate recommendations for dahlia based on trial results along with an extension fact sheet regarding dahlia production and nutrient recommendations for Utah growers and the public.

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CHAPTER II

AN URBAN SOIL SURVEY OF TRACE ELEMENTS AND ORGANIC CONTAMINANTS ALONG THE WASATCH FRONT

Abstract. Urban soil contamination has become an increasing concern within residential developments and with the expansion of urban agriculture. Urban agriculture has grown across the United States, and there are currently 39 community gardens and urban farms in Salt Lake County alone, with more currently in development. The purpose of this study was to conduct an urban soil survey along the Wasatch Front to examine the concentrations of common contaminants in urban farms and community gardens during 2020-2021. The contaminants of focus for this study were trace elements, mainly lead and arsenic, along with organic contaminants: petroleum hydrocarbons, polycyclic aromatic hydrocarbons, and volatile organic carbons. Site selection included an emphasis on urban gardens in Salt Lake County, along with sites with a greater potential for soil contamination from historical land use, such as historical orchards, and the distance between sites and the nearest roadways were measured as well. Measured concentrations were compared to EPA regional screening levels (RSL) and nationwide background levels. Lead concentrations ranged from 14.8 to 516 mg kg^{-1}, with a mean concentration of 91.76 mg kg^{-1}, while arsenic ranged 2.83 to 39.31 mg kg^{-1} (mean of 11.8 mg kg^{-1}), all of which exceeded the EPA RSL of 0.68 mg kg^{-1}. Benzo (A) pyrene was the primary hydrocarbon contaminant of concern, and concentrations that were above detectable limits ranged from 0.01 to 0.44 mg kg^{-1}, with a mean concentration of 0.09 mg kg^{-1}. By

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determining the baseline degree of soil contamination in key urban agricultural sites along the Wasatch Front, local screening levels were developed to soil management plans for producers.

Introduction

In the past 30 years, the number of urban farms grew by 30% across the US (Siegner et al., 2018), and in the 2017 USDA Census of Agriculture, urban farms accounted for nearly 15% of all US farms (Rangarajan et al., 2019). In Western states experiencing rapid population growth, such as Utah, the mean farm size decreased by almost 80 hectares from 1997 to 2007, while the total number of farms increased from approximately 13,000 farms in 1990 to 16,600 in 2010 (Utah Agricultural Sustainability Task Force, 2011). The growth of community gardens has been also substantial over the last two decades. Approximately 6,000 community gardens were established across 38 US cities in 1996, and by 2010, national estimates approached 10,000 (Lee, 2010). A five-year study from the National Gardening Association also found the number of households involved in some form of food gardening increased from 36 million in 2008 to 42 million in 2013, representing approximately 35% of all US households (National Gardening Association, 2014).

With the growth of urban farms and gardens, soil quality is becoming increasingly important, particularly as underutilized, vacant spaces are considered for food production (Kaiser et al., 2015). These urban areas are often at a higher risk for soil contamination compared to rural areas, as urban areas are more densely populated, industrialized, and heavily trafficked by automobiles, which can contribute to soil contamination (US EPA, 2011). Common contaminants of concern include lead, arsenic, and hydrocarbons, and methods of exposure from soil include inhalation, ingestion, and dermal contact (US EPA, 2020). Guidance levels for soil concentrations are typically based upon a cancer-risk approach; the US EPA set regional screening levels (RSLs) on a cancer risk of 10^{-6}, which is a risk level that assumes one in a million individuals will develop cancer over a lifetime exposure to a certain dose. (Teaf et al., 2010). Two methods of evaluating cancer risk from contaminants include oral slope factors (SFO) that estimate the likelihood of developing cancer with lifetime oral exposure to a contaminant, and inhalation unit risks (IUR) that evaluate the probability of developing cancer from constant exposure to a contaminant in the air (US EPA, 2020).

Lead and arsenic are two trace elements commonly associated with soil contamination. Lead contamination can be attributed to leaded gasoline, lead paint, lead-arsenate pesticides, or point-source emitters, such as smelters and mine tailings (US EPA, 1998), while anthropogenic sources of soil arsenic include chromated copper arsenate (CCA) treated wood, sewage sludge, and point source emitters (Belluck et al., 2003). In soils, lead and arsenic are highly immobile, and can persist in the soil for thousands of years (Saxena et al., 1999; Shacklette and Boerngen, 1984; Washington State Department of Health, 1999), highlighting the need for assessment of site histories when developing space for food crop production. The U.S. EPA RSL is 400 mg kg^{-1} for total soil lead and 0.68 mg kg^{-1} for total soil arsenic (Table 2.1), while the mean background concentration for the conterminous United States is 16 mg kg^{-1} for lead and 5.2 mg kg^{-1} for arsenic (US EPA, 2020; Shacklette and Boerngen, 1984). Compared to lead, guidance levels for arsenic vary widely by state, with ranges from 0.039 to 40 mg kg^{-1} across the US (Teaf et al., 2010). This indicates that while assessing sites and developing management plans around lead are relatively straightforward, arsenic assessment and management requires more regional analysis.

Urban exposure to lead is a common concern, as city redevelopment can mask former industrial areas and traffic densities are greater than rural and less disturbed areas. For example, in New York City, NY, the mean concentration of lead in parks and other recreational areas with historic industrial use was 320 mg kg^{-1}, while areas without prior industrial use averaged 105 mg kg^{-1} (Pavilonis et. al, 2020). A New York community garden that was adjacent to two moderately trafficked roads had a mean lead concentration of 816 mg kg^{-1} (Paltseva, 2019), while soil along Interstate-75 in Ohio averaged 410 mg kg^{-1} (Turer et al., 2001) and soil within 1.6 km of Interstate-880 in California averaged was 568 mg kg^{-1} (Teichman et al., 1993). These studies highlight the degree to which lead can be elevated in urban environments across the US, and areas that may be assumed to be uncontaminated can be significantly elevated above natural background levels.

Point source emitters, such as smelters and mine tailings, are also common sources of contamination in industrial cities. In Philadelphia, Pennsylvania, the mean lead concentration for sites with a history of industrial smelting activity was $2.12*10^3$ mg kg^{-1}, while the mean concentration in residential areas with no industrial history was 261 mg kg^{-1} (Lusby et. al, 2015). In Ontario, Canada, soil lead concentrations within 15-180 m of a secondary lead smelter ranged from 3,564 to 28,000 mg kg^{-1}, with concentrations decreasing with increasing distance (Bisessar, 1982). In Poland, four sites within 1 to 6 km of a former copper smelter ranged in total soil lead from 65 to 130 mg kg^{-1}, with the lowest value occurring at the greatest distance away (Kabala and Singh, 2001). In Salt Lake County, Utah, elevated arsenic levels were found up to a distance of 10 k at the Kennecott Garfield copper smelter, which was estimated to have emitted arsenic and other pollutants from 1906 to 1978, and concentrations ranged from 5-540 mg kg^{-1} with the greatest concentrations occurring within 3 km of the smelter (Ball et al., 1983). Industrial point source emitters have the potential to significantly contaminate on-site soil and elevate broader areas above natural background levels.

Lead arsenate ($PbHAsO_4$), a pesticide applied to orchards up until the late 1940s, is a common source of both lead and arsenic contamination and has chemical composition that allows for elevated levels to persist long after the pesticides were last applied (Codling et. al, 2015). In Washington, soils on or within 60 m of historical orchards had median lead and arsenic concentrations of 65.9 mg kg^{-1} and 7.0 mg kg^{-1}, while those beyond 60 m had median concentrations of 7.8 and 2.8 mg kg^{-1} (Wolz et. al, 2003). A former orchard in North Carolina with a history of known lead arsenate use was repurposed into a residential community in the 1990s, and mean lead concentrations ranged 480 to 930 mg kg^{-1}, while the mean arsenic ranged 91 to 240 mg kg^{-1} (Embrick et al., 2005). Though lead arsenate use was phased out in the 1950s, the nature of both contaminants allows for this chemical to remain a significant source of contamination in areas where it was applied.

Other persistent sources of arsenic include Chromated copper arsenic (CCA) leached from treated lumber, as well as leaks and spills at treatment facilities, though the lumber industry and the EPA agreed to discontinue CCA-treated wood for residential structures in 2003 (Zagury et al., 2003). In Montreal, Canada, total arsenic concentrations from soil adjacent to CCA-treated poles ranged 5.3 to 410 mg kg^{-1}, and the concentrations decreased significantly by a 0.5m depth and 0.5m distance from the pole (Zagury et al., 2003). Soils under nine residential decks in Florida ranged in total arsenic from 1.18 to 217 mg kg^{-1}, with a mean of 28.5 mg kg^{-1} at a depth of 0.025 m (Townsend et al., 2003). Soil in the upper 5 cm under seven decks in Connecticut had a median arsenic concentration of 76 mg kg^{-1} and a range of 3-350 mg kg^{-1}, with concentrations decreasing with increasing distance from the decks (Stilwell and Gorney, 1997). CCA-treated wood has strong potential to enrich surface soil arsenic, however, areas of concern are often directly below or adjacent to the source of leaching.

Like trace elements, hydrocarbon contaminants can occur naturally or through anthropogenic enrichment, and include polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs), and polychlorinated biphenyls (PCBs) (Srivastava et al, 2019). Natural sources include through forest fire, diffusion of hydrocarbons from petroleum-rich rock, and biosynthesis from organisms, while anthropogenic contamination often results from the burning of fossil fuels or other organic compounds, or through the spillage and/or leakage of petroleum compounds (Srivastava et al, 2019). The EPA RSL for benzo (A) pyrene, a common hydrocarbon contaminant, is 0.11 mg kg^{-1}, and the lifespan and mobility of hydrocarbons in the soil is largely based on the molecular weight of the compound (Banger et al., 2010). Examples of low molecular weight PAHs include naphthalene and anthracene, which have a biodegradation half-life of 3and 123 days (Banger et al., 2010; US EPA, 2020), while benzo (A) pyrene and chrysene are two examples of high molecular weight PAHs, with biodegradation half-life lives of 224 and 378 days (Banger et al., 2010; US EPA, 2020).

The burning of fuel and the leakage of petroleum chemicals from automobiles also contribute to hydrocarbon contamination in soil (Srivastava et al., 2019.) In Puducherry, India, the concentration of soil adjacent to mechanic workshops along a major highway ranged from 91.72 to 121.79 mg kg^{-1}, while agricultural soils located alongside highways ranged from 44.94 to 83.4 mg kg^{-1} (Khan and Kathi, 2014). In Brisbane, Australia, soils within 0.5 m from a road with a daily traffic count of 35,600 vehicles per day had a mean total hydrocarbon concentration of 3.35 mg kg^{-1} (Yang et al., 1991). In particular, the concentration of Benzo (A) pyrene decreased with increasing distance from the road, as the mean concentration decreased from 0.36 mg kg^{-1} at 0.5 m to 0.08 mg kg^{-1} at 15 m away (Yang et al., 1991). In Delhi, India, industrial and roadside soils had mean benzo (A) pyrene concentrations of 0.56 and 0.37 mg kg^{-1}, respectively, while samples taken from residential and agricultural sites resulted in means of 0.11 and 0.06 mg kg^{-1}, respectively (Singh et al., 2012). A pasture adjacent to a highway with a traffic value of 70,000 vehicles per day in France had a mean total PAH concentration of 2.6 mg kg^{-1} at a 10 m distance away, which decreased to 1.1 mg kg^{-1} at a 150 m distance (Crépineau et al., 2003). Similarly, the mean concentration of Benzo (A) pyrene was 0.2 mg kg^{-1} 10 m from the highway, 0.07 mg kg^{-1} at 50 m, and 0.05 mg kg^{-1} at 150 m. (Crépineau et al., 2003). These case studies indicate the risk of hydrocarbon contamination from automobile traffic can be relatively localized and establishing minimum distances for food crop production from roadways by traffic density may help establish safe protocols for urban gardens and farms.

In Salt Lake County, Utah, 18 community gardens are a resource to thousands of people, while urban farming programs for refugees cover 7.2 hectares and sell produce.

As these and other programs expand, soil contamination is an increasing challenge and financial burden, as no protocols to screen for contaminants exist in Utah, most sites have not been tested, and background levels have not been established. Therefore, the overall goal of this study was to conduct an urban soil survey of these community gardens and farms to address the local needs of soil contamination screening. The objectives included: 1) collaborate with key urban farm and garden leaders to select priority sites for the urban soil survey, and 2) investigate soil quality and contamination by assessing the concentrations of trace elements, primarily lead and arsenic, along with hydrocarbons, with a focus on benzo (A) pyrene, with regional risk factors and site histories.

Materials and Methods

Site Selection. From November 2020 to June 2021, 20 sites were sampled along the Wasatch Front in Utah. Two sites were in Cache County, a 22.6-ha orchard established in 1904, therefore at risk for lead arsenate pesticide contamination, and a 0.91-ha community garden for refugees (Table 2.2). The other 18 sites were in Salt Lake County (Table 2.2), with ten sites managed by Wasatch Community Gardens that ranged in size from 0.11 – 12.8 ha, seven operated by the International Rescue Committee for refugee start-to-farm programs that ranged in size from 0.12-9.61 ha, and one urban farm for a charter high school that was 4.3 ha. ESRI ArcGIS pro was used to map sites and evaluate site proximity to any identified risk factors (ESRI Inc, 2022).

Survey sites were selected based on risk factors for elevated contaminant concentrations that included: buildings on site built before 1978; sites within five km of former and/or current industrial areas such as smelters, factories, and mine sites; land adjacent to roadways; and land located on former or current orchards that were in production at or before the late 1940s. Community gardens using native soil were also targeted, as contamination risk may be greater than gardens with raised beds. The number of people using each garden or farm was also considered, with greater priority given to sites with greater activity.

Sites were further prioritized based on needs assessments in collaboration with Wasatch Community Garden and the International Rescue Committee - New Roots program leaders. (Wasatch Community Gardens, 2022; International Rescue Committee, 2022). The land use history of each site was evaluated for historic risk factors. The aerial imagery collection from 1937 to 1964 through the Utah Geologic Survey (UGS, 2021) was examined to identify former industrial areas, such as smelters and mine sites, the presence of pre-1950 orchards, areas that were residential pre 1978 that may be at risk for lead paint, along with land adjacent to roadways. The native soil properties of each site were also investigated using the NRCS Web Soil Survey (USDA-NRCS, 2021), though six sites in Salt Lake County were classified as urban land, thus no background information was available.

Sampling sites were also classified based upon roadway traffic data. The distance from each site to roadway was quantified with GIS and this proximity was divided into five classes, with class five within the closest distance from a roadway (Table 2.3). Site proximity was also compared to the Annual Average Daily Traffic (AADT) data, as well as nine traffic level classifications adapted from Wasatch Front Regional Council (WFRC) and Utah Department of Transportation (UDOT) traffic counts. A dual score was also calculated per site, as the product of the road proximity and traffic scores (Table 2.4)

Sites listed on the EPA National Priorities List (NPL) were mapped to assess potential industrial point-source effects on site contamination (US EPA, 2022). The EPA NPL list distinguishes three categories of either current sites, proposed sites, or deleted sites; eleven sites exist in the Salt Lake City area. Contaminants of concern varied among the listed sites, but common contaminants among the sites included arsenic, lead, copper, and zinc. The locations of gardens and farms were assessed according to a 5 km buffer around each superfund site (US EPA, 2020) and the distance between each NPL and sampling site was measured in ArcGIS PRO to compare soil test levels with distance from the listed NPL sites.

Soil Sampling and Analysis. One to six composite soil samples were collected from each site, depending on the site size, mapped soil series, previous land management, and present soil management. Sites were first zoned by soil series mapped by the NRCS Web Soil Survey, with each series designated as a zone for one composite sample. Zones were further delineated based on any differences in historic land use or management practices. For large sites (3.64 to 22.8 ha) with no differences in mapped soils, land use, or current management, the soil was randomly sampled across the fields. For the smaller community gardens (0.11 to 0.28 ha) that were designed with raised beds or in-ground plots managed by individual families, approximately 50% of the beds were subsampled per composite sample. The targeted sample depth was 0 to 0.3 m for trace elements and soil quality, while 0.3-0.6 m samples were collected when key risk factors were identified on site: proximity to heavily trafficked areas, former or current industrial sites, the presence of residences with lead paint, or presence of an historic orchard. The composite samples were dried at 60°C, ground, and sieved through a 2 mm mesh (Reisenauer,1978). Utah State University Analytical Lab conducted the EPA 3050 total elemental test + ICP analysis for all samples (US EPA, 1996). Soil sampled for hydrocarbon analysis was collected from the surface to a 0.3 m depth, according to laboratory protocols of the Chemtech-Ford Laboratories which tested the samples in this study by EPA method 8260D for petroleum analysis and hydrocarbons and the EPA method 8270-SIM for polycyclic aromatic hydrocarbons (US EPA, 2006; US EPA, 2014).

The degree of soil contamination at each site was compared to EPA RSLs and different state guidance levels, along with the geoaccumulation index (Igeo) (Förstner and Müller, 1981). Igeo is calculated from Förstner and Müller (1981) as**:**

$$\boldsymbol{Igeo = ln\frac{Cn}{1.5*Bn}} \qquad \textbf{(1)}$$

where Cn is the measured value of the trace element of interest, Bn is the geochemical background value that is multiplied by 1.5 to account for natural background variation. Igeo <0 indicated soil was uncontaminated soil, 0 to 1 indicated uncontaminated to moderately contaminated, 1 to 2 indicated moderately contaminated, 2 to 3 was moderately to heavily contaminated, 3 to 4 was heavily contaminated, 4 to 5 was heavily to extremely contaminated, and >5 was classified as extremely contaminated (Förstner and Müller, 1981).

Results

Site Characteristics. Among the 20 sites sampled in Salt Lake County, 76% were located within a 5 km radius of an EPA NPL superfund site. 57% of the sites sampled were adjacent to trafficked roadways with 2,000 to 47,000 vehicles per day, while 19% of sites had historical structures on the property prior to 1978, based on historical aerial imagery. Elevated risk factors that were unique to individual sites included previous land uses as a parking lot, gas station, or neighborhoods with a history of smelting activity.

Lead. Across sites, the mean (±standard error, SE) and median total lead concentrations were 91.8 (±20.7) and 61.3 mg kg^{-1}, with a range of 14.8 to 516 mg kg^{-1} (Table 2.5). One site was above the EPA RSL of 400 mg kg^{-1} and seven sites were above California's guidance level of 80 mg kg^{-1} (Figure 2.1). The Igeo ranged from -0.5 to 3.0, while the mean and median were both 0.9 (Figure 2.2).

The mean (±SE) lead concentration for sites within 5 km of an EPA NPL site was 97.5 (±16.3) mg kg^{-1} compared to 47.9 (±7.3) mg kg^{-1} for those outside. Correlations between individual site concentrations and distance to each NPL site ranged from 0.01 to 0.06, and no strong relationships were observed in regards to any of the NPL sites which had a history of smelting activity (Figure 2.3). For sites with pre-1978 buildings in historic aerial imagery, the mean (±SE) lead concentration was 101.9 (± 29.5) mg kg^{-1}, and lead was 81.9 (±15.2) mg kg^{-1} for sites without. Lead concentrations displayed no correlation to the dual traffic score, with a correlation coefficient of 0.05 and an R^2 of 0.0028. For the lone apple orchard that was sampled, the mean lead concentration was 17.5 mg kg^{-1}. Sites near the downtown Salt Lake City area showed the greatest soil text values, as five out of seven sites with concentrations above 80 mg kg^{-1} are located within this area (Figure 2.1).

Arsenic. The overall mean (±SE) and median arsenic concentrations were 11.8 (±1.6) and 8.97 mg kg^{-1}, with a range of 2.8 to 39.3 mg kg^{-1}. All samples were above the EPA RSL of 0.68 mg kg^{-1}. Igeo values ranged from -1.1 to 1.6, with a mean and median of 0.2 and 0.08. Sites within 5 km of an NPL site had a mean arsenic concentration of 11.9 (± 2.3) mg kg^{-1} ,while samples from sites outside of the 5 km radius gave a mean of 10.5 (±1.6) mg kg^{-1} . All sample sites displayed weak to no correlation to the distance to each NPL site, however half of the sites with soil above 12 mg As kg^{-1} were near the downtown Salt Lake City area. Arsenic displayed a moderate to strong correlation to the dual traffic score with a correlation coefficient of 0.59 and an R^2 value of 0.35. The mean concentration of the apple orchard was 9.5 mg kg^{-1}, above the EPA RSL but similar to screening levels based upon natural background levels.

Benzo (A) Pyrene. 52% of sites were below detectable limits for all hydrocarbons. Sites with detectable benzo (A) pyrene ranged from 0.01 to 0.44 mg kg^{-1}, with a mean and median concentration of 0.09 (±0.04) and 0.03 mg kg^{-1}. Two samples were above the EPA RSL of 0.11 mg kg^{-1}, and three samples were greater than California's guidance value of 0.063 mg kg^{-1}. Specifically, sites within the 5 km NPL buffer averaged 0.11 (± 0.03) mg kg^{-1}, while sites outside of the buffer averaged 0.03 (± 0.01) mg kg^{-1}. Like lead and arsenic, weak to no correlation was observed in regard to contaminant levels and the distance to each NPL site. Sites at risk for enrichment from lead paint, averaged 0.21 (± 0.1) mg kg^{-1}, while the sites designated as low risk for lead paint averaged of 0.04 (± 0.006) mg kg^{-1}. The relationship between measured concentrations and the dual traffic score was weak, with a coefficient of 0.28 and an R^2 value of 0.08.

Discussion

Soil lead was greater at sites that were within 5 km of an NPL site or those where structures were determined to be present before 1978, compared to those outside of the 5 km buffer or without the pre-1978 building histories. The weak correlation between lead concentrations and the dual traffic score indicated that vehicle exhaust or runoff, and general traffic, presented lower risk. The absence of any sites that were well above the EPA RSL suggests that the elevated lead may not be attributed to one specific source but rather may be the result of a combination of non-point sources across Salt Lake County, as many common sources of contamination have the potential to contaminate wide areas at levels above natural backgrounds but well below guidance values. For example, elevated levels above a background lead concentration of 10 mg kg^{-1} were detected at distances of 40 to 65 km from a lead smelter in Port Pirie, South Australia (Cartwright et al., 1977). Even though sites not directly adjacent to roadways often pose little risk in terms of contamination, emissions from vehicles can also lead to concentrations that are still above natural backgrounds, as contamination from vehicle emissions has been detected up to 50 m from a roadway (Kibblewhite, 2018). Sites near downtown Salt Lake City exhibited greater contamination levels compared to outside of the city, which could be a combination of the higher density of NPL sites along with higher overall traffic densities and city emissions. While the sites were largely below the lead risk thresholds set by EPA RSL standards, the soil test levels established that these urban environments were elevated above background levels, thus soil screening is an important consideration with the growth in urban farming.

In contrast to the relatively low total lead across sites, mean total arsenic was an order of magnitude greater than the screening level set by the EPA, which is also lower than most natural background levels. With a mean arsenic concentration at 6.3 mg kg^{-1} greater than the natural background concentration for the western United States, local screening levels are needed in Utah that balance health risk and applied management. States that base screening levels upon natural background levels by region may be more practical for management, though they do not incorporate cancer-based risk (Jennings, 2010). Common recommendations when soil test arsenic is above the EPA RSL, but below the regional background levels, include avoiding production of leafy greens or root vegetables, as arsenic can accumulate in leaves and crop skin that is in contact with the soil (McBride et al., 2013; Paltseva et al., 2018). Production of crops in which the fruit or seeds are consumed (e.g. tomatoes, corn) are generally safer as uptake by the plant is minimal and there is less contact with bare soil (McBride, 2013). Moreover, practical practices like the washing of food and equipment are also important because soil concentrations near background levels can still pose risk.

The moderate to strong correlation between measured arsenic concentrations and the dual traffic score was greater than that of lead and benzo (A) pyrene, though enriched soil lead and PAHs are more commonly associated with vehicle emissions. While arsenic contamination has been found to be low risk in terms of vehicle traffic, arsenic present through atmospheric deposition of other sources can still be spread through the agitation of road dust (Dousova et al., 2020). The mean arsenic concentration was also elevated within the 5 km NPL buffer, compared to those outside it, which supports other research that found NPL sites have potential to contaminate at greater distances than typical buffer areas, depending on factors such as wind direction, rain, and topography (Cartwright et al., 1977). Our measured arsenic concentrations could be a result of the above factors, as the highest contamination occurred in areas with the overlapping superfund buffers and higher traffic densities.

Nearly half of the urban farms and community gardens were below the detectable limits for benzo (A) pyrene, which may be attributed to the short and volatile lifespan of hydrocarbons in soil compared to lead and arsenic (EPA, 2020). One of the primary sources of hydrocarbon contamination is the combustion of fuel and other organic compounds (Srivastava et al., 2019), but only a weak correlation existed between soil concentrations and the distance to roadways and daily traffic. All of the sites in this study were greater than 10 m away from a roadway, while previous research targeted land directly adjacent to a road (Kim et al., 2019) and found soils approached background levels within 5 to 10 m away from a road (Zehetner et al., 2008). Moreover, subsamples for each composite were collected across each site, which may dilute road effects. Future sampling guides may consider zoning sites by proximity to roadways, with one composite collected within 10 m of a roadway, if crops may be grown there. Alternatively, planning a 10 m buffer from roads into urban garden and farms design may also help mitigate safety risks.

All sites had elevated total lead concentrations above natural background levels, and most were below the EPA RSL, yet above state guidelines that use stricter, health risk-based screening levels, such as those set in California and Maryland (CA DSTC, 2020; MDE, 2020). Total concentrations are a useful metric for initial soil surveys of an area and can be used a basis for additional testing to determine the bioavailable fraction, as higher total concentrations yield greater bioavailable concentrations (Misenheimer et al., 2018). Because lead generally has a low bioavailability, particularly in alkaline soils

(Martínez and Motto, 2000), one of the primary exposure pathways occurs through direct contact with the soil, typically through ingestion, inhalation, and dermal contact (Shayler et al., 2009). As all sites were either community gardens, urban farms, or future garden or farm sites, exposure risk may be minimized by practical methods, such as washing hands after working a garden and rinsing food crops before consumption as soil particles may stick to food grown in the gardens (Shayler et al., 2009). Moreover, at sites in which the total lead was below the EPA RSL but above more stringent state guidelines (e.g. 80, 200 mg kg^{-1}), further recommendations can include avoiding root and leafy green crop production, as root vegetables have the most contact with the soil and leafy greens have been shown to accumulate lead more than root or fruit crops (Feleafel and Mirdad, 2012).

While sites were generally considered uncontaminated to moderately contaminated, practical management and risk prevention methods are still important, as the sites were above natural background levels. More localized screening limits should be employed in order to evaluate arsenic contamination in a practical way, and this could also be done for lead to help better evaluate soils that are below the EPA RSL but elevated above other state screening levels. Proper development of such screening levels can help growers distinguish soils in which management may just amount to the washing of hands and hood from those that may require stricter measures, such as limitations on certain crops or even the capping of soil.

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Table 2.1: Federal and state soil screening levels for arsenic, lead, and benzo(A)pyrene in mg kg^{-1}.

Federal and State examples	**Lead**	**Arsenic**	**Benzo(A) pyrene**
	-------------------- mg kg^{-1}		**--------------------**
EPA Regional Screening Level (RSL)[1]	400	0.68	0.11
California[2]	80	0.07	0.063
Maryland[3,4]	200	0.43	0.11
New York[5]	400	16	1.0
Texas[6]	500	24	4.1
Colorado[7]	400	0.68	0.11
New Mexico[8]	400	3.9	0.62
Wyoming[9]	400	0.68	0.11
Idaho[10,11]	400	0.68	0.14

([1]EPA, 2020; [2]Ca DSTC, 2020; [3,4]:MDE, 2020; [5]NYCRR, 2006; [6]TDEQ, 2021; [7]CDPHE, 2021; [8]NMED, 2006; [9]WDEQ, 2021; [10,11]IDEQ, 2018).

Table 2.2: A summary of the urban soil sampling sites along the Wasatch Front in Utah, by city, stakeholder, and contaminant risk factors.

Site Number	City	Operator	Risk factor	Soil map unit[1]
		Cache County		
1	River Heights	Historic Orchard	Historical orchard site	RhB, TmB, SwD
2	Logan	Community Garden	Low risk	SvA
		Salt Lake County		
3	Salt Lake City	Community Gardens	Traffic, old residential site	UL
4			High traffic	UL
5			Garden underperforms	TaB
6			Former parking lot	UL
7			Traffic	Ch
8			Salinity issues	De, Lk
9			Traffic, old residential area	UL
10			Former gas station on site	UL
11	Magna		Industrial area with smelting history	Ch
12	Sandy		Traffic	1000
13	Salt Lake City	Urban Farms	Traffic	KdA
14	Draper		Low risk	1000, TuB
15	Glendale		Traffic, PAHs previously identified	UL
16	Holladay		Traffic	TuB
17	Salt Lake City		Low risk	Du
18	Salt Lake City		Low risk	Ch
19	Millcreek		Low risk	KdA
20	Salt Lake City	High School	Traffic	Mc

[1] Soil map units from the NRCS Soil Web Survey (2021). UL is an unclassified urban land designation, while the remaining abbreviations represent mapped soil series: RhB is Ricks gravelly loam, TmB is Timpanogos silt loam, SwD is Sterling gravelly loam, Sva is Steed gravelly loam, TaB is Taylorsville silty clay loam, Ch is Chipman silty clay loam, De is Deckerman fine sandy loam, Lk is Leland fine sandy loam, 1000 is Parleys loam, KdA is Kidman very fine sandy loam, TuB is Timpanogos loam, Du is designated as dumps land, and Mc is Magna silty clay.

Table 2.3. Class divisions assigned 1 to 9, with 9 being greatest risk, based on the average annual daily traffic (AADT) in vehicles per day and the site proximity to the nearest road in m.

Class	AADT[1] (Vehicles per day)	Road proximity[2] (m)
1	<6,000	>50
2	6,000-18,000	26-50
3	18,000-36,000	16-25
4	36,000-72,000	11-15
5	72,000-120,000	<10
6	120,000-160,000	
7	160,000-200,000	
8	200,000-240,000	
9	>240,000	

[1] AADT ranges delineated by WFRC (2021); [2] Road proximity ranges adapted from Rodríguez-Flores and Rodríguez-Casstellón (1982).

Table 2.4: Survey site number and corresponding traffic information, including the average annual daily traffic (AADT) in automobiles per day and AADT Class ranking from 1 to 9, with greater numbers representing greater traffic. Site proximity to the nearest road in m is also given with Road Proximity Class, ranked from 1 to 5, with greater numbers indicating closer proximity to roadways. The dual score is the product of the Traffic and Road Proximity classes, with greater numbers representing greater risk.

Site No.	County	AADT[1] (Vehicles per day)	AADT Class[1]	Road Proximity (m)	Road Proximity Class	Dual score
1	Cache	2889	1	20	3	3
2	Cache	5009	1	98	1	1
3	Salt Lake	15487	2	15	4	8
4	Salt Lake	47119	4	15	4	16
5	Salt Lake	13187	2	140	1	2
6	Salt Lake	2230	1	75	1	1
7	Salt Lake	NA	1	48	2	2
8	Salt Lake	75533	5	40	2	10
8	Salt Lake	75533	5	40	2	10
8	Salt Lake	75533	5	40	2	10
9	Salt Lake	NA	1	19	3	3
10	Salt Lake	47312	4	19	3	12
11	Salt Lake	NA	1	270	1	1
12	Salt Lake	NA	1	14	4	4
13	Salt Lake	NA	1	140	1	1
14	Salt Lake	13000	2	65	1	2
15	Salt Lake	17387	2	84	1	2
16	Salt Lake	14739	2	20	3	6
17	Salt Lake	NA	1	50	2	2
18	Salt Lake	NA	1	110	1	1
19	Salt Lake	NA	1	55	1	1
20	Salt Lake	NA	1	30	2	2

[1] Data from WFRC (2021)

Table 2.5. Arsenic, lead, and benzo (A) pyrene concentrations in mg kg^{-1} for each survey site, the median and mean across the survey, and the EPA Residential Screening Level (RSL).

Sample Number	**Arsenic**	**Lead**	**Benzo(A) pyrene**
	---	**mg kg^{-1}**	----------------------------
1	10.6	20.1	NA[2]
2	8.5	14.8	NA[2]
3	2.8	15.3	NA[2]
4	5.8	58.3	0.031
5	8.6	91.7	NA[2]
6	39.3	130.3	0.014
7	6.3	32.0	<0.0082
8	5.5	55.5	0.034
9	13.0	155.8	0.028
10	7.0	32.1	<0.0071
11	8.1	77.0	<0.0084
12	7.1	48.	<0.0073
13	7.9	188.0	0.16
14	28.4	69.6	0.44
15	15.9	516.0	NA[2]
16	16.8	43.6	<0.0077
17	25	19.2	NA[2]
18	14.5	274.0	<0.0077
19	8.0	70	0.0092
20	8.4	55.8	<0.0076
21	10.4	143.0	0.088
22	9.9	44.2	<0.0073
23	9.7	25.9	0.041
24	7.3	64.2	<0.0085
25	12.5	64.9	NA[2]
26	9.4	76.1	<0.0084
Median	9.0	61.3	0.034
Mean	11.8	91.8	0.094
US EPA RSL[1]	0.68	400	0.11

[1]EPA (2021); [2]Sites not sampled for hydrocarbons due to site location or sample depth.

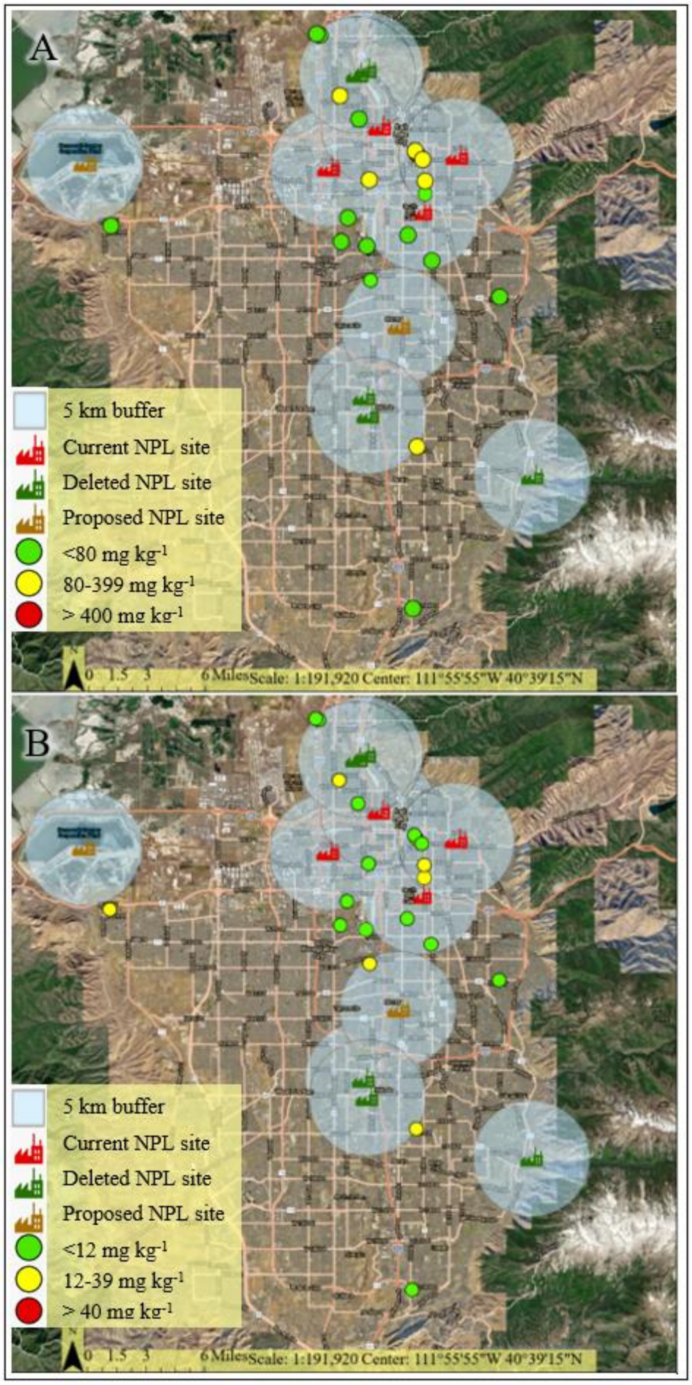

Figure 2.1: Measured trace element levels by site in Salt Lake County, Utah, for total soil A) lead and B) arsenic relative to categorized EPA NPL site (industrial markers) with red markers indicating a current NPL site, green representing sites deleted from the list, and brown representing a proposed NPL site. Each NPL site includes a 5 km buffer (blue circles). The soil test levels include red, when concentrations were above EPA RSL limits for lead, yellow for concentrations above developed local recommendations, and green, which is below local guidance levels.

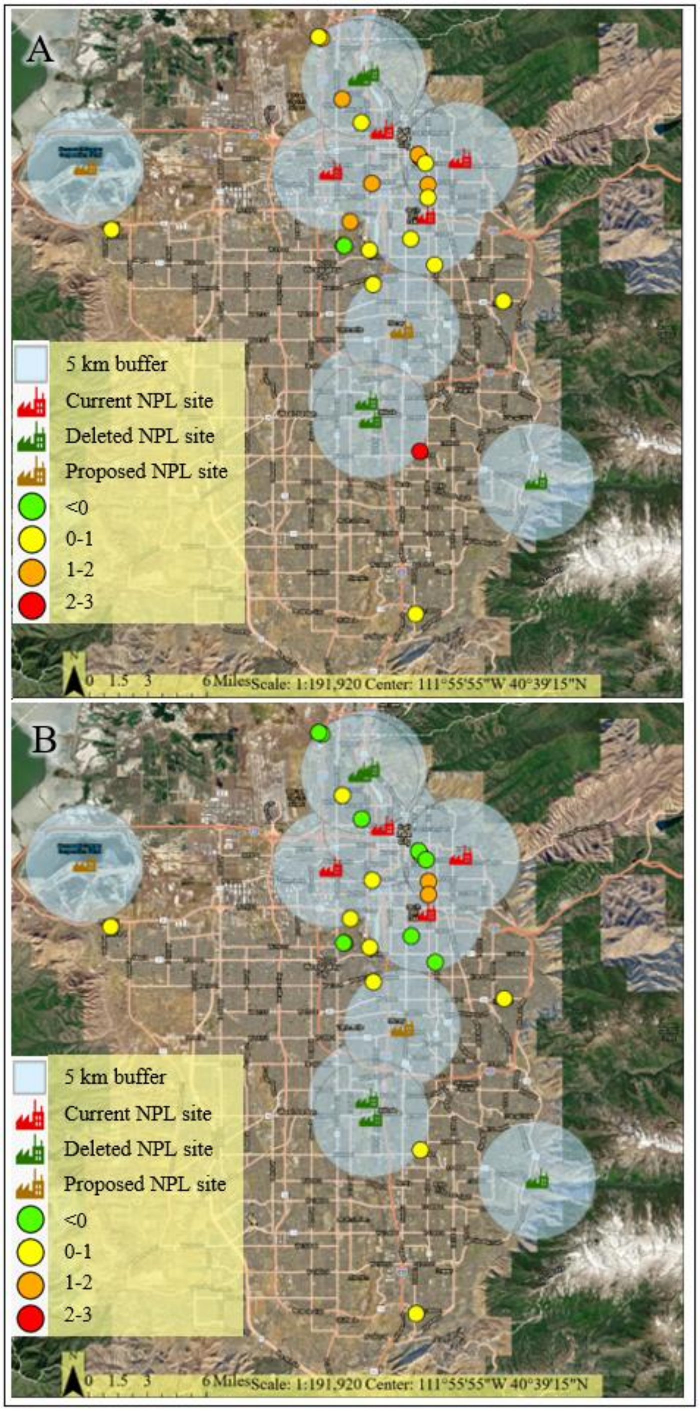

Figure 2.2: Igeo values by site in Salt Lake County, Utah, for A) lead and B) arsenic, relative to EPA NPL sites (industrial markers) with red markers indicating a current NPL site, green representing sites deleted from the list and brown representing a proposed NPL site. Each NPL site includes a 5 km buffer (blue circles). The site Igeo categories include red, which indicated moderate to heavy contamination, orange for moderate contamination, yellow for soils that are uncontaminated to moderately contaminated, and green for uncontaminated soils.

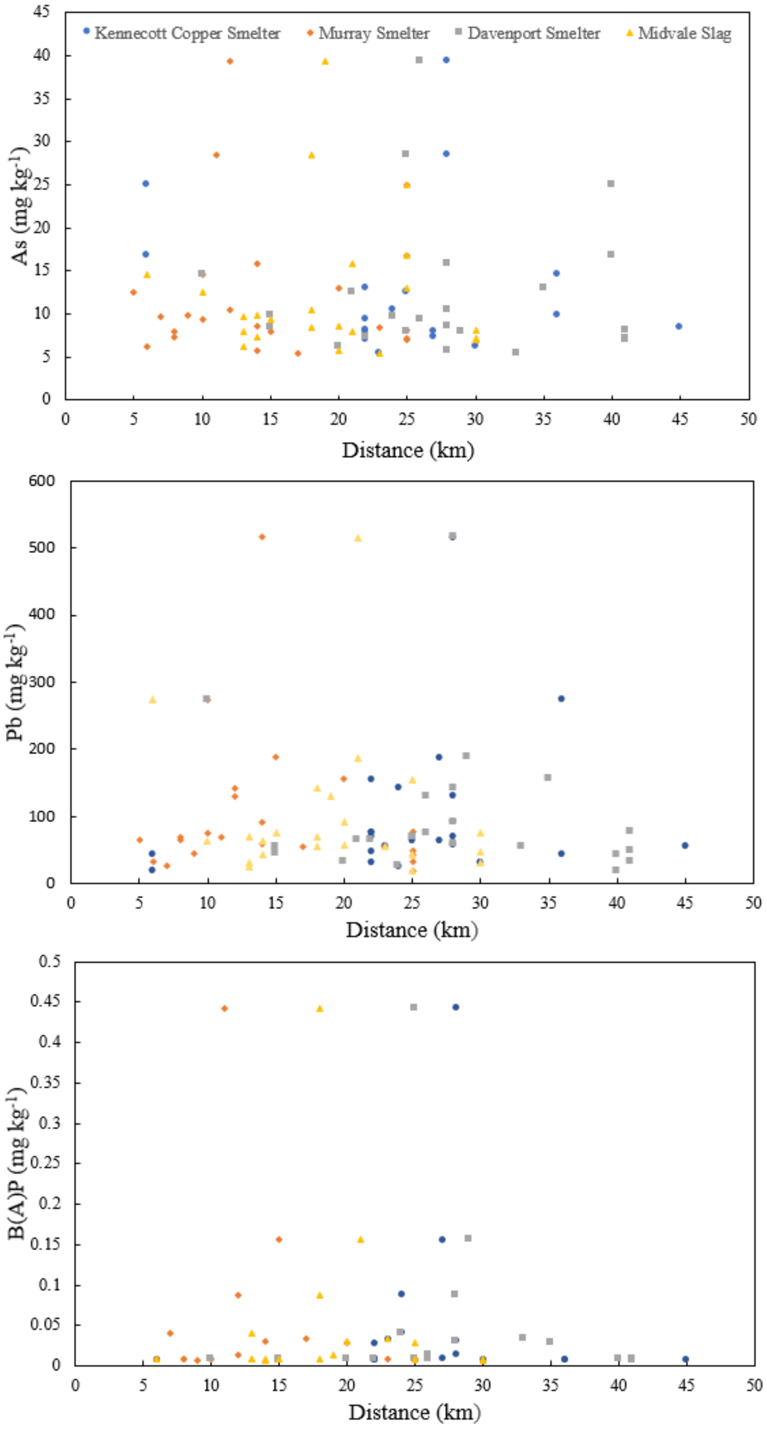

Figure 2.3: Total soil concentrations of arsenic (As, top), lead (Pb, middle), and benzo (A) pyrene (B(A)P), bottom) in mg kg^{-1} for each site and its distance to each EPA NPL smelting activity site in km.

CHAPTER III

A SURVEY OF SOIL QUALITY IN URBAN AGRICULTURE ACROSS UTAH

Abstract. Over-application of nutrients is a concern across agricultural systems, as this can lead to higher input costs, runoff pollution, and elevated soil salinity. However, the potential for overfertilization and monitoring of subsequent effects have been well documented in large-scale, conventional farms, but are often looked over urban micro-farm settings, including community gardens. With the growth in urban agriculture in Utah, the purpose of this study was to conduct a soil survey of small farms and gardens along the Wasatch Front to examine primary macronutrient levels and general soil quality parameters, such as soil salinity, total carbon, and pH. The mean nitrate-nitrogen concentration for all sample sites was 36 mg kg^{-1}, while the mean Olsen P and K concentrations were 87.2 and 331.5 mg kg^{-1}, respectively. Salinity levels ranged from 0.72 to 11.8 dS m^{-1} with a mean value of 3.21 dS m^{-1}, while total carbon ranged from 1.61 to 10.56% with a mean concentration of 4.69%. Primary macronutrient levels were generally optimal to excessively high, particularly soil test phosphorus that was three times greater than regional recommendations. Most farm and garden leaders indicated an emphasis on the use of compost and manure. These excessive macronutrient concentrations demonstrate the need for further outreach to small farms and gardens that outlines environmentally sustainable nutrient management.

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Introduction

The total number of urban farms has increased by 30% since 1989, (Siegner et al., 2018), and 15% of all farms in the country are estimated to be urban farms according to the 2017 USDA Agricultural Census. (Rangarajan and Riordan, 2019). In Utah specifically, the total number of farms increased from approximately 13,000 farms in 1990 to 16,600 farms in 2010, while the mean farm size has decreased by almost 80 hectares 2since 1997 while (Utah Agricultural Sustainability Task Force, 2011). There has also been a demographic shift to urban areas. In Utah, 40% of the population lived in urban areas in 1900, and by 2010, this value increased to 90% (Utah Agriculture Sustainability Task Force, 2012). These statistics show that while the number of larger, more traditional farms have decreased, the total number of farms has increased, which could potentially be attributed to the growth of urban farms and community gardens as a result of population growth in urban areas.

The growth of community gardens has been substantial over the last two decades. The number of community gardens increased from 6,000 to 10,000 from 1996 to 2010(Lee, 2010). A five-year study from the National Gardening Association also found the number of households involved in some form of food gardening increased from 36 million in 2008 to 42 million in 2013, which represents approximately 35% of all US households (National Gardening Association, 2014). In Utah, there are an estimated 39 community gardens along the Wasatch Front. Common concerns of community gardeners include access to land as the most common challenge among community gardens, while soil contamination, safety, water, and funding were also highlighted (Guitart et al., 2012).

Nutrient management in urban agriculture often emphasizes organic fertilizers and amendments – particularly manures and composts – over mineral salt-based fertilizers used in conventional agriculture (Metson and Bennet, 2015). Many urban farmers and community gardeners favor compost and manure because of the high organic matter content that can improve soil structure; water infiltration, retention, and drainage; and nutrient levels (Taylor and Lovell, 2014). The use of compost can also help reduce the bioavailability of lead and other trace element contaminants, which are more common in urban environments than in rural areas (McBride et al., 2015; EPA, 2020). Soil fertility management in urban environments can be both sustainable and beneficial to the soil when amendments are applied properly.

Despite the benefits, nutrient management in urban agriculture commonly faces challenges with over-application of amendments, which can result in excessive soil test levels. Over fertilization of nitrogen (N) and phosphorus (P) were examined among urban farms in the Twin Cities metropolitan area in Minnesota, where the median annual application rates were 1400 kg N ha^{-1} and 300 kg P ha^{-1}, and plant-based composts were found to be the most commonly applied nutrient source (Small et al., 2019). As a result, soil test P (by the Bray-P 1 Method) averaged 80 ppm, which was significantly greater than optimal P levels of 21-30 mg kg^{-1} for garden soils (Small et al., 2019). Of 21 sites sampled in Chicago, Illinois, the macronutrient concentrations were elevated, with median soil test P and potassium, K (by the Bray-P 1 Method and Mehlich III extraction), levels ranging from 94.3 to 225.4 mg kg^{-1} and 345 to 936 mg kg^{-1}, respectively, while the recommended soil test K values were 126-300 mg kg^{-1} (Ugarte and Taylor, 2020). In the Netherlands, the form and number of amendments in urban agriculture sites was compared to conventional agriculture limits. The mean application rates were 789 kg N ha^{-1} yr^{-1} and 267 kg P or P_2O_5 ha^{-1} yr^{-1} across the urban farms, while standard application limits for the conventional agriculture were 209 kg N ha^{-1} yr^{-1} on clay soils and 75 kg P ha^{-1} yr^{-1} on soils with low phosphorus contents (Wielemaker et al., 2018). These case studies highlight that overapplication of nutrients is common in urban agriculture, which presents challenges for on-farm nutrient losses to runoff and leaching, as well as an inefficient use of financial resources.

Currently, there is more of a regulatory focus for nutrient management in large-scale agricultural operations compared to smaller urban farms and community gardens. According to the National Agricultural Law Center (2020), 48 states have laws requiring nutrient management plans, but these laws target animal feeding operations (AFO) and confined animal feeding operations (CAFO). The EPA defines an AFO as a lot or facility where animals will be contained and fed for more than 45 days in a one-year period and where crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season in any portion of the facility, while CAFOs are determined by the number of livestock present at a site (EPA, 2021). Because regulations are not designed to limit nutrient application in community garden or urban farm settings, many small, urban farms tend to follow more societal ideals and place limits on the form of fertilizer applied rather than the amount. Wasatch Community Gardens, one of the largest operators of community gardens in the Salt Lake City area, does not allow the use of mineral fertilizers such as urea and superphosphate, and they recommend the use of organic fertilizers that can be sourced locally, such as composts and manures. In addition to the focus on the forms of soil amendments to meet internal garden or farm guidelines, outreach is needed to also bring attention to the amount of nutrients applied.

The use of organic fertilizers such as manures and compost have the potential to lead to higher phosphorus levels compared to the application of mineral fertilizers. When Olsen-P was compared across soils with excessive application of organic versus mineral-salt fertilizers in Shanghai, China, organic fertilizers increased Olsen P from 54 to 86 mg kg^{-1} over a four-year period, while mineral fertilizers increased Olsen-P levels from 55 to 72 mg kg^{-1} (Song et al., 2017). In a comparison of manure-based versus municipal- food-waste-derived composts in Saint Paul, Minnesota, compost application rates were 36 times greater than the crop demand for P, resulting in increased input costs and runoff risk (Small et al., 2018). Manure-based composts leached significantly more P, with a maximum leaching value of 0.95 g P 0.3 m^{-2}, compared to 0.2 g P 0.3 m^{-2} for municipal sources (Small et al., 2018). Excessive compost and manure applications have the potential to elevate macronutrient levels compared to similar applications of mineral fertilizers, and excessive applications may also lead to other soil quality issues, such as elevated salinity levels(Gondek et al., 2020).

In semi-arid to arid climates, over application of compost and manure may also increase soil salinity, which is often naturally elevated (Jordán et al., 2004). Use of manure-based sources, which have an average of 1.5 dS m^{-1} greater than municipal and plant-based sources (Stock et al., 2019), present further risk. Therefore, overapplication of compost on small, urban farms in semi-arid climates presents an additional challenge to soil management, as maintaining soil salinity levels less than 2 dS m^{-1} is needed for optimal production of most horticultural crops (Stock et al., 2020). In Utah, as urban microfarms and community gardens grow, a need for soil testing exists to establish baseline soil test levels, inform recommendations for small farms, and develop outreach tools that help reshape public perceptions of sustainable soil management. Therefore, the overall goal of this study was to test for elevated macronutrient levels and associated soil quality parameters, such as salinity and pH, to help reduce any unneeded nutrient applications along with the risk of nutrient pollution and salinity elevation.

Materials and Methods

From November 2020 to June 2021, 31 urban farm and garden sites were sampled across the Wasatch Front in Utah, where most urban microfarms and community gardens are located. The sites represented the following counties from north to south: three sites in each Cache and Davis Counties; one site in each Box Elder, Juab, and Weber Counties; and 22 across Salt Lake County, which is the densest county for urban microfarms (Figure 3.1). 19 sites were community gardens and urban farms that were primarily cropped for vegetable production and ranged in size from 0.11 to 12.8 ha. One site was a 22.6 ha orchard that had been in production since 1904, while the remaining 11 sites were cut flower farms (Table 3.1).

One to six composite soil samples were collected from each site to a depth of 0.3 m, and the number of samples collected depended on the site size, mapped soil series, historic land use, and present soil management. Sites were first zoned by soil series mapped by the NRCS Web Soil Survey (Soil Survey Staff, 2021), with each series designated as a zone for one composite sample (Stock et al., 2020). Zones were further delineated based on any differences in historic land use or management practices, which were determined through analysis of aerial imagery from the Utah Geologic Survey (UGS, 2021). For large sites (3.64 to 22.8 ha) with no differences in mapped soils, land use, or current management, four to five subsamples were collected across fields and combined into one composite sample. For the smaller community gardens (0.11 to 0.28 ha) that were designed with raised beds or in-ground plots managed by individual families, approximately 50% of the beds were subsampled per one composite sample. Cut flower farms averaged 0.14 ha. NRCS descriptions of the mapped series at each flower farm resulted predicted a pH range of 6.5 to 8.8.

The composite samples were dried at 60°C, ground, and sieved through a 2 mm mesh (Reisenauer, 1978). Utah State University Analytical Lab (USUAL, 2022) conducted the following soil tests: pH, salinity (EC), Sodium Adsorption Rate (SAR), Nitrate N 2N KCL extract, Olsen P and K, Total Carbon, and texture by the hydrometer method (Rhoades, 1982; Knepel, 2003; Olsen and Sommers, 1982, Sheldrick and Wang, 1993).

Results

Across sites, nitrate-nitrogen concentrations ranged from 4.85-158 mg kg^{-1}, with a mean and median concentration of 42.3 (± 7.0) and 26.9 mg kg^{-1}. Soil test phosphorus ranged 12.8 to 205 mg kg^{-1} with a mean and median concentration of 98.8 (±9.9) and 102.5 mg kg^{-1}, and soil test potassium ranged from 107 to 1051 mg kg^{-1}, with a mean and median of 435.0 (± 43.9) and 364 mg kg^{-1} (Table 3.2). Among the sites in vegetable production, 76% were above the optimal limit for phosphorus, while 60% were above optimal potassium levels. 100% of the flower farms sampled were above the optimal soil test phosphorus range, while 90% were above the optimal range for potassium (Figure 3.2). 52% of vegetable production sites had excessive phosphorus, while 90% of flower garden sites had excessive phosphorus concentrations.

Soil pH ranged from 7.0 to 8.0, while the mean and median values were both 7.4. Soil salinity ranged from 0.73-9.98 dS m^{-1} with a mean and median value of 2.9 (± 0.40) and 2.14 dS m^{-1}. The soil salinity of 59% of the vegetable garden sites was above 2 dS m^{-1},while 26% of the sites were greater than 4 dS m^{-1}. 45% of the flower farms were above the 2 dS m^{-1} threshold, and 27% were above the saline soil threshold of 4 dS m^{-1}. The total carbon range was 1.61-10.56%, with a mean and median of 4.69 and 3.94%.

Nitrate-nitrogen concentrations were highly correlated with phosphorus concentrations and moderately correlated with potassium, with correlation coefficients of 0.72 and 0.66, respectively. Soil test phosphorus and potassium were low to moderately correlated with a coefficient of 0.43, while nitrogen and phosphorus were both moderately to strongly correlated with total carbon percent, with a coefficient for nitrogen and total carbon at 0.76 and phosphorus and total carbon at 0.63. Potassium was weakly correlated to total carbon with a coefficient of 0.29. When compared to soil salinity, the coefficients for nitrogen, phosphorus, potassium, total carbon, and pH were 0.18, 0.07, 0.04, and 0.12, respectively. Total carbon and pH showed a moderately strong negative relationship with a correlation coefficient of -0.72, while nitrogen and phosphorus both exhibited weak negative relationships with pH, as seen in the coefficients of -0.37 and -0.32.

Discussion

The average macronutrient concentrations across all urban sites were elevated well above optimal levels for Utah, with recommended levels of >25, 21 to 30, and 126 to 300 mg kg^{-1} for N,P, and K, respectively (Cardon et al., 2008). The average soil test phosphorus concentration across all sites was nearly three times greater than the maximum limit for the recommended range, while the average potassium concentration was 50% above the highest limit in the recommended range. These consistently greater phosphorus and potassium concentrations across sites demonstrates excessive application of amendments. Continuous application of nutrients above optimal levels results in unnecessary nutrient costs and could potentially lead to nutrient runoff.

Measured total carbon was elevated compared to natural levels in Utah topsoil (Soil Survey Staff, 2022), supporting farm records regarding use of amendments high in organic matter, primarily compost. Most composts and solid manures have equal parts of N, P and K (Pant et al., 2012), which can result in high to excessive soil test phosphorus when application rates are based on N needs (Sadeghpour et al., 2016). Without regulation, soil fertility tends to be managed more intuitively across community gardens and urban microfarms, as regular soil testing is less common in small-scale agriculture (Witzling et al., 2010). All community gardens, for example, left nutrient management decisions up to the individual families for their specific plots. Other than prohibiting conventional fertilizers, no guidelines were provided and application rates were not monitored. However, given that most were considered organic and, paired with the increased total soil carbon compared to native levels and high soil test nitrogen and phosphorus, the nutrient levels likely resulted from application of organic amendments, such as manure and compost, which are strongly favored as “natural” sources among the public. This was also seen in the flower farms, which reported the use of composts and manures, along with amendments such as fish emulsion and bone meal.

Both the mean and median soil salinity values were above the recommended 2 dS m^{-1} threshold for most vegetable and ornamental crop production, however the relationships between soil salinity and the other soil quality parameters measured were weak. Eight sites were above the 4 dS m^{-1} threshold for saline soils, which can significantly reduce the overall quality and yield of many horticultural crops that were grown at these sites. The addition of compost and manure amendments can further elevate the salinity (Li-Xian et al., 2007), therefore growers should use caution when applying nutrient amendments, especially if they are using manure or composts derived from animal manure, which are already high in salts (Stock et al., 2019).

The soil test results highlight the need for continued outreach and extension, especially in increasing the awareness for continued soil testing and calculating application rates. One of the major community garden organizations in Salt Lake County recommends that growers conduct soil tests if applying phosphorus amendments, such as bone meal or soft phosphorus. However, soil testing before the application of composts and manures is not mentioned, despite the well-documented effect of enriched soil test phosphorus when these amendments are over-applied (Sadeghpour et al., 2016). This is especially important for the long-term soil sustainability in Utah, as long-term manure and compost use can lead to soil salinization in arid or non-irrigated conditions (Hao and Chang, 2003). While compost and manure are beneficial amendments, Cooperative Extension outreach is needed to bring awareness regarding nutrient management via common composts and manures, and potential secondary effects that may stem from the overapplication of these amendments.

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Table 3.1: Summary of sampled sites along the Wasatch front by crop, soil type, and the size of the site**.** Soil textures determined by hydrometer method and site sized estimated in ESRI ARCGIS Pro.

Site Number	Crop Type	Soil Type	Site Size (ha)
Cache County			
1	fruit	loam	22.6
1	fruit	loam	22.6
2	cut flower	loam	0.1
3	vegetable	loam	0.71
Box Elder County			
4	cut flower	loam	0.3
Weber County			
5	cut flower	clay loam	0.1
Davis County			
6	cut flower	loamy sand	0.1
7	cut flower	sandy loam	0.1
8	cut flower	silt loam	0.3
9	cut flower	loam	0.1
Salt Lake County			
10	vegetable	loam	0.24
11	vegetable	loam	0.12
12	vegetable	sandy loam	0.12
13	vegetable	sandy loam	0.18
14	vegetable	loam	0.3
15	vegetable	loam	12.9
16	vegetable	loam	0.27
17	vegetable	sandy loam	0.15
18	vegetable	loam	0.21
19	vegetable	sandy loam	0.19
20	vegetable	sandy loam	1.41
21	vegetable	sandy loam	9.63
22	vegetable	sandy loam	0.8
23	vegetable	sandy loam	0.8
24	vegetable	loam	0.2
25	vegetable	loam	0.05
26	vegetable	loam	0.025
27	vegetable	silty clay loam	2.0
28	cut flower	clay loam	0.05
29	cut flower	silty clay	0.12
30	cut flower	loam	0.1
Juab County			
31	cut flower	loam	0.2

Table 3.2: Concentrations of soil test nitrate-nitrogen (NO_3-N), Olsen phosphorus (P) and potassium (K), total carbon, salinity, and pH for each sampled site by county, with median and mean levels across the study and state recommendations.

Site Number	**Olsen-P**	**Olsen-K**	**NO_3-N**	**Total Carbon**	**Salinity**	**pH**
	---------------- mg kg^{-1}		**-----------**	%	**(dS m^{-1})**	
Cache County						
1	30.2	239	15.7	2.93	0.73	7.5
1	23.8	234	8.53	3.77	1.26	7.3
2	107	609	37.3	-	1.53	7.4
3	50.3	131	21.5	7.25	1.26	7.2
Box Elder County						
4	176.5	512	20.9	-	1.46	7.4
Weber County						
5	205	723	61.6	-	2.01	7.8
Davis County						
6	74	188	6.7	-	1.44	7.7
7	132	371	14.4	-	0.9	7.6
8	118	1051	158	-	3.3	7.2
9	76.4	396	13.9	-	1.39	8.0
Salt Lake County						
10	160	900	153	10.56	2.92	7.1
10	68.7	338	21.7	4.00	1.17	7.4
11	25.8	315	16	3.96	1.69	7.0
12	77.2	176	13.6	3.92	1.18	7.4
13	198	329	52	7.04	1.63	7.0
14	78.5	328	47.3	6.19	2	7.2
15	12.8	107	7.23	1.94	2.9	7.4
15	15.5	159	11	5.61	9.98	7.1
15	17.4	214	12.8	2.43	4.79	7.4
16	155	347	48.9	7.63	2.11	7.1
17	120	149	13.8	5.88	2.48	7.2
18	138	599	30.9	2.56	3.93	7.5
18	46.9	671	19.4	1.61	3.82	7.7
19	48.2	316	31.2	2.40	1.92	7.5
20	119	116	38.1	3.32	4.01	7.3
21	22.6	120	16.4	1.28	2.17	7.4
22	49	357	4.85	3.05	0.93	7.7
23	37.4	543	19.4	3.30	1.56	7.4
24	196	410	106	7.80	5.8	7.3
25	100	357	39.7	3.92	2.54	7.4
26	174	511	45.9	4.79	2.58	7.4
27	151	678	86.3	6.69	4.59	7.2
28	50.2	590.5	57	-	4.48	7.7
29	105	901	54.9	-	6.1	7.6
30	114	899	134	-	6.55	7.7
Juab County						
31	139	380	22.9	-	1.79	7.5
Median	89.3	357	22.3	3.96	2.48	7.3
Mean	94.7	424	40.6	4.77	2.89	7.3
Recommended[1]	21-30	126-300	>25	--	--	--

[1] Cardon et al., 2008.

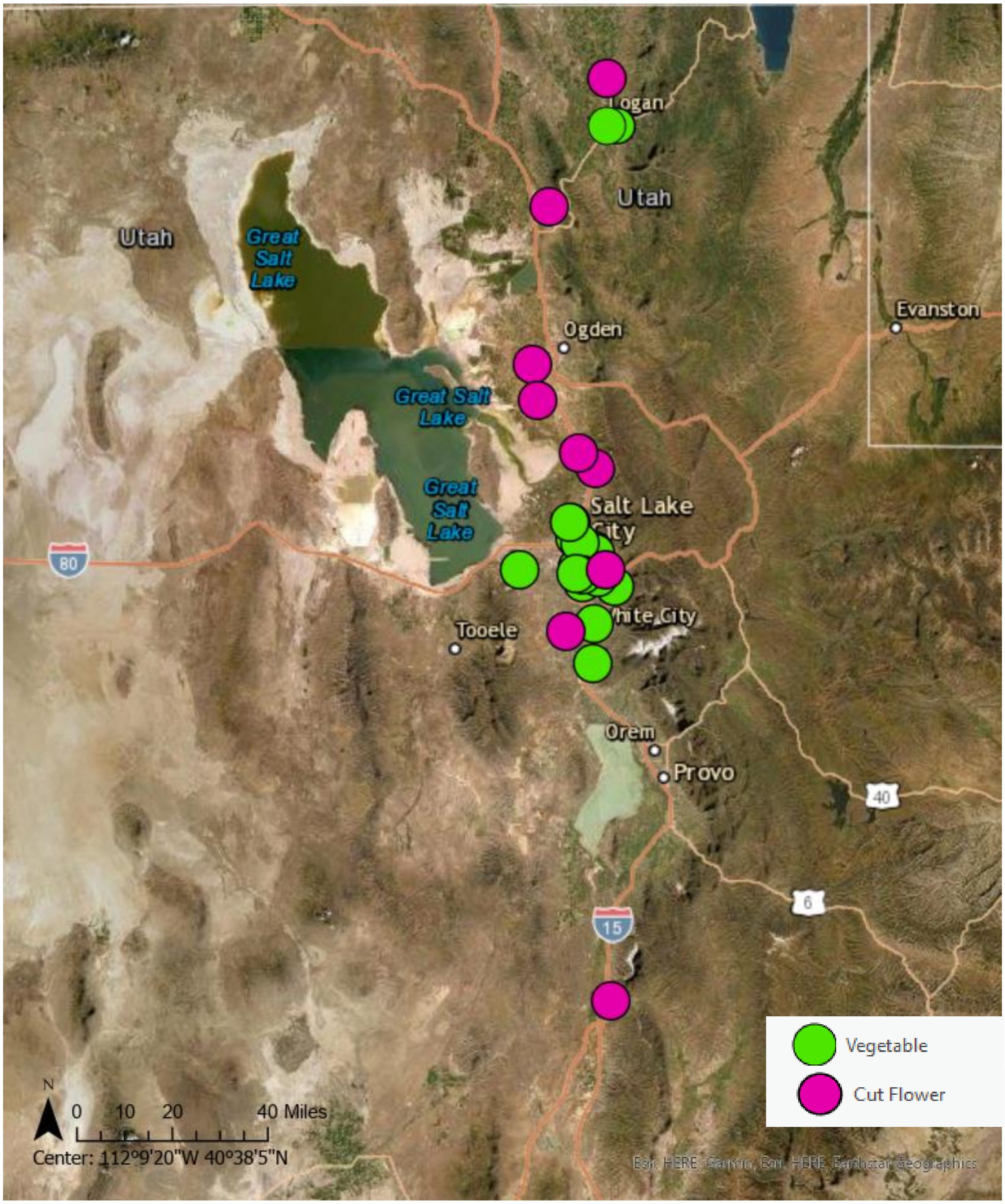

Figure 3.1: Map of sites in Northern Utah with counties delineated with orange lines. Sites were designated by the main crop type, with green circles indicating predominantly vegetable production and pink circles indicating cut flower farms.
[1]ESRI Inc., 2022

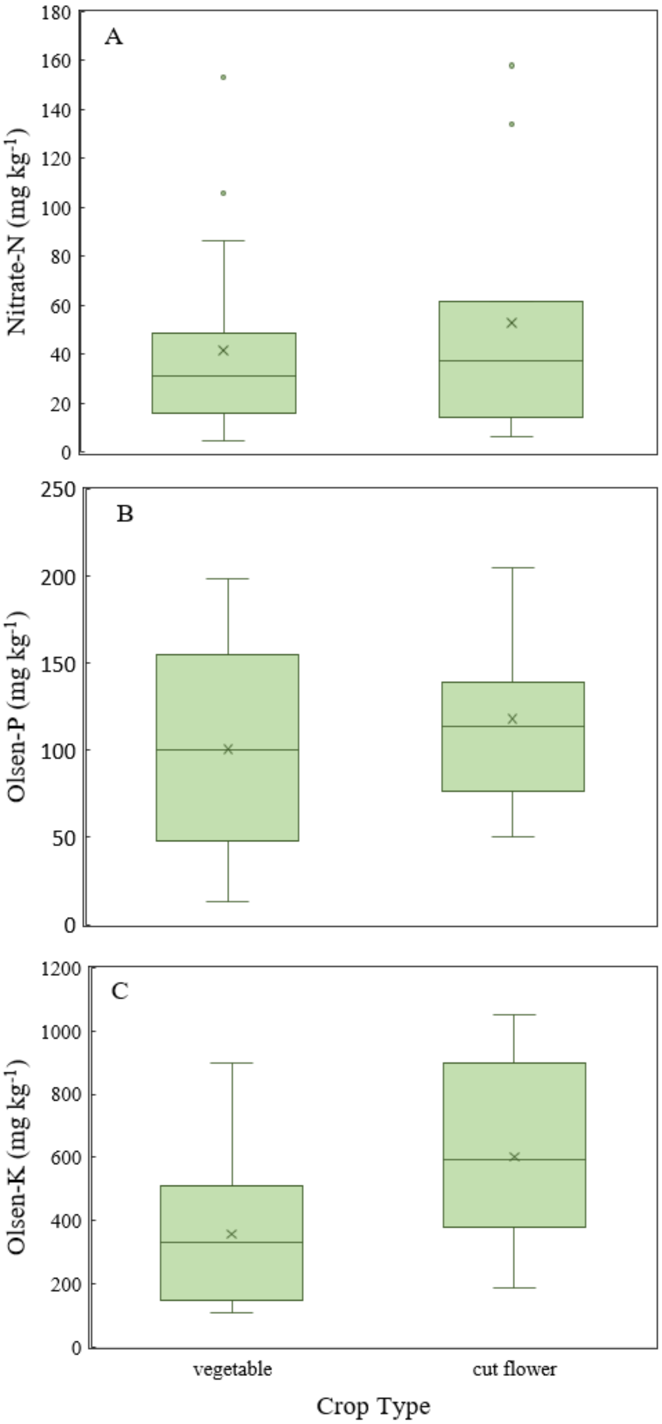

Figure 3.2: Primary macronutrient levels in mg kg^{-1} plotted by primary crop type, with A) Nitrate-N, B) Olsen-Phosphorus (P), and C) represents Olsen Potassium (K). The mean is denoted by the marker while the median is the center line, and the 25 and 75th percentiles are the upper and lower ends of the box. The minimum and maximum values are denoted by the end of each whisker or outlier value.

CHAPTER IV

THE EFFECTS OF VARYING NITROGEN RATES ON DAHLIA YIELD AND PRODUCTION

Abstract. Cut flowers have strong profit potential in small farm settings, and dahlias are particularly sought-after as a local crop for their size and appearance. However, nutrient management research for dahlia is limited, especially for climates and soil types in the Western United States. The purpose of the study was to evaluate the growth and yield response of the popular cultivar ‘Café au Lait’, to increasing nitrogen rates to determine guidelines for field dahlia production in Utah. Dahlia yield and quality was measured over a three-year field trial with five nitrogen application rates: 0 (control), 56, 112, 168, and 224 kg N ha^{-1}. A grower participant study was also conducted across Northern Utah to better understand dahlia yield response and cultural practices. The 168 and 224 kg N ha^{-1} application rates produced similar yields in 2021, and the 168 kg N ha^{-1} application was found to be the most economic efficient option based upon its yield and general budget assumptions. Plant mortality rates were high in 2019 and 2020, due to the high prevalence of virus in the plants. Plant survivability was much greater in 2021, and visual virus symptoms were not as prevalent compared to the first two years. Soil test results from the grower participant study showed elevated macronutrient and soil salinity levels, especially when compared to the field trial. While virus incidence presented confounding factors during the first two study years, this study helps establish optimal nitrogen rates at 168 kg N ha^{-1}, while increasing awareness regarding virus prevalence in industry and the

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need for routine testing and additional research, as well as nutrient management outreach with small growers.

Introduction

The increasing demand for cut flowers has led to a rapid growth of flower farms across the US. According to the 2015 Floriculture Crops Summary, the number of growers increased by 5% in top producing states from 2014 to 2015, and the domestic wholesale market was valued at $374 million (USDA-NASS, 2016). Membership in the Association of Specialty Cut Flower Growers (ASCFG) also reflects the recent growth of farms at the national level, as membership has increased from 1,401 to 2,553 in the last two years (personal communication, Judy Laushman, 29 June 2021). In the U.S. Mountain West, the number of cut flower micro farms has increased, particularly in Utah, where 105 farms established in the last five years, at a rate of approximately 30 new cut flower farms per year (Stock, unpublished data). The Utah Cut Flower Farm Association (UCFFA) established in 2019 and has grown to 125 members (UCFFA, 2022). Local growers have targeted specialty cut flowers, prioritizing production of flowers that do not transport well and have a relatively short vase life for direct-to-consumer sales through farmers markets and community-supported agriculture (CSAs) (Shimizu-Yumoto and Ichimura, 2013). These cut flowers offer a premium profit potential with minimal land requirements for urban agriculture, with net returns of flowers, such as snapdragons and peonies averaging $27.00 per m^2 (Lewis et al., 2021).

With the current increases in urban farming and cut flower production, particularly in new regions for production, such as the US Intermountain West, locally adapted production recommendations are important for optimizing yield. In 2020, 85% of surveyed cut flower growers in Utah identified a lack of regional guidelines as the main challenge for cut flower farming in the state (Survey of cut flower growers by M.N. Stock, 5 March 2020), as the climate, soils, and water quality vary from conditions in the traditional coastal hubs. Dahlias (*Dahlia sp.)* are particularly challenging for growers, yet widely grown in Utah, with 87% of farms relying on dahlias as a primary summer to fall flower crop (Curtis, Stock, and the UCFFA, unpublished). Dahlias ship poorly and have strong consumer demand, thus commanding premium market pricing, with wholesale receipts averaging $4 to $5 per stem (Stock, 2020). Moreover, in a 2021 survey of florists across Utah, 89% listed dahlia as the top crop to source from local farms (Curtis, Stock, and the UCFFA, unpublished), highlighting the importance of dahlia to the state.

Dahlias are tuberous, herbaceous perennial plants within the Asteraceae family and are native to Mexico (Schie, 2013). In temperate climates (e.g., USDA Hardiness Zones 7 and cooler), dahlias are grown as annuals during the frost-free growing season, typically from late May to early October in Northern Utah (Utah Climate Center, 2021). Though *Dahlia* is a diverse genus with 42 recognized species (American Dahlia Society, 2021), *D. pinnata* is primarily used for cut flower production, with common bloom types for cut flower production including dinnerplate, cactus, ball, and pompom (Vernon, 2014). Dinnerplate varieties produce some of the largest dahlia blooms, with flower diameter reaching 0.3 m and plants reaching 2.4 m in height (Chandraju et al., 2013). Though dinnerplate varieties are highly marketable and bloom continuously until first frost, bloom initiates later in the season (e.g. August – September) compared to other bloom types, resulting in challenges with yield (Mariña, 2015), particularly in mountain climates that are prone to early and less predictable first frost dates. Dahlia ‘Café au Lait’, a dinnerplate variety with a pink to cream bloom that reaches a 0.25 m diameter, is particularly popular in Utah with strong local demand commanding premium pricing ($4 to $5 per stem wholesale), but the onset of flowering is typically late and growers report less vigorous yields than other varieties.

When evaluating bloom timing, nutrient management, particularly higher nitrogen (N) application rates, may lengthen the period to first bloom due to increased vegetative growth, which can be measured by factors such as plant height and number of leaves per plant. The American Dahlia Society (2001) recommends 195 kg N ha^{-1} and states growers commonly apply 2-3 times more fertilizer than needed, which can reduce yield by 25 %. Research-based recommendations vary, with most ranging from 50 to 100 kg N ha^{-1} (Gani et al, 2007; Sheergojri et al., 2013; Barik, 2017; Prasad et al, 2019), though none have been conducted in regions with conditions similar to the U.S. Mountain West. A field study in Allahabad, India assessed bloom timing of ‘Kenya Yellow’, a dinnerplate type, and found that an80 kg N ha^{-1} application rate resulted in the first bud appearance occurring at 73.3 days, while first bud in the control (0 kg N ha^{-1}) occurred at 68.9 days, though comparing one rate to a zero application control introduces challenges with bloom timing in response to plant stress factors (Wada and Takeno, 2010). With a fertilizer N rate of 80 kg ha^{-1}, 37.0 leaves were produced per plant and the mean plant height was 46.5 cm, compared to 27.6 leaves per plant and a 36.4 cm plant height at the control rate (Gani et al., 2007). Other research determined applications of 75 kg N ha^{-1} produced a mean plant height of 70.8 cm with ‘Pink Attraction’, a decorative type, compared to a plant height of 61.6 cm at 50 kg N ha^{-1} and 70.7 cm at 100 kg N ha^{-1} (Sheergojri et al., 2013). Other studies indicate that modest nutrient application rates may not delay first bloom. Applying fertilizer at a rate of 50 kg N ha^{-1} , 60 kg P_2O_5 ha^{-1}, and 50 kg K_2O ha^{-1} with 50 kg ha^{-1} vermicompost resulted in first bloom occurring at 50.5 days for ‘Eternity Sports’, while first bloom occurred at 60.1 days with the control rate of 0 kg N ha^{-1} (Barik, 2017). Similarly, first flower opening of ‘Kenya Orange’, occurred at 57.4 days with fertilizer application rates of 75 kg N ha^{-1} 90 kg P_2O_5 ha^{-1} 75 kg K_2O ha^{-1} and 1.25 t ha^{-1} vermicompost, while the control (0 kg N ha^{-1}) required 73.1 days (Prasad et. al, 2018). Previous research regarding fertilizer rates and the timing to first bloom had ranging results, but relatively low N rates were tested and comparison to zero-application controls is challenging to interpret for farm recommendations.

Along with total yield, quantifying stem length and bloom diameter are important, as these are graded for pricing across wholesale and retail markets. In assessing yield with greenhouse production of ‘Kenya Yellow’, a mean of 6.6 flowers per plant and flower size of 186 mm was produced at a fertilizer rate of 80 kg N ha^{-1}, compared to a mean of 2.6 flowers per plant and a 141 mm diameter in the unfertilized control (Gani et al., 2007). With ‘Kenya Orange,’ a mean of 9.9 flowers per plant and a 220 mm flower diameter were produced at applications of 75 kg N ha^{-1} 90 kg P_2O_5 ha^{-1} 75 kg K_2O ha^{-1} with 1.25 t ha^{-1} of vermicompost, while a mean of 6.6 flowers per plant and flower diameter of 172 mm were produced in the unfertilized control (Prasad et. al, 2018). With fertilizer application rates of 50 kg N ha^{-1} 60 kg P_2O_5 ha^{-1} 50 kg K_2O ha^{-1} with 50 kg ha^{-1} of vermicompost, ‘Eternity Sports’ produced a mean total yield of 10.1 flowers per plant, stem length of 250 mm, and bloom diameter of 251 mm, while the control produced 5.3 flowers per plant, a stem length of 121 mm, and a bloom diameter of 185 cm (Barik, 2017). Though these studies establish the benefit of nutrient application for greenhouse production of dahlia, more research is needed to test a range of non-zero rates that include greater applications of nitrogen and determine whether greater yield is possible.

Testing nutrient management under field conditions is also important for developing fertilizer recommendations for small farms, which largely rely on outdoor production. In Raleigh, North Carolina (USDA Hardiness Zone 7b to 8a, 1168 mm annual precipitation), 0 to 336 kg ha^{-1} N fertilizer rates were tested with one to three split applications across zinnia, cosmos, sunflower, and celosia (Ahmad et al., 2012). High N rates did not delay time to first bloom for any of the crops, while higher N significantly increased stem length for cosmos and sunflower, but not for celosia or zinnia (Ahmad et al., 2012). This highlights the need to establish crop-specific recommendations for field cut flower production. Moreover, developing regional guidelines is needed to account for differences in climate and soil type, hence nutrient retention. In Logan, Utah (USDA Hardiness Zone 5b, 472 mm annual precipitation) farmers face unique growing conditions (USDA ARS, 2012; US Climate Data, 2022). In this high elevation and semi-arid climate, the soils are alkaline, soil salinity can be elevated, and nutrient retention can persist in fine-textured soils, as leaching is lower than in areas with greater precipitation (Hao and Chang, 2003). Therefore, to improve production of dahlia in the U.S. Mountain West, local field trials are needed to establish nutrient management recommendations.

Dahlias are susceptible to different viruses, and virus symptoms were noticed in local stock along with larger, nationwide wholesale stock suppliers before the trial was started and as the trial continued. Common viruses include Dahlia Mosaic Virus (DMV), Impatiens Necrotic Spot Virus (INSV), Tobacco Streak Virus (TSV), and Tomato

Spotted Wilt Virus (TSWV). DMV is commonly identified by chlorosis mosaic patterns on the leaves, and it can result in necrosis and stunting of the plant (USU extension, 2020). INSV is another disease that can be identified by yellowing and necrotic spots on leaves, and it can also lead to stunting of the plant (Moorman, 2011). TSV can be identified by necrotic streaks on leaves and chlorosis, while TSWV can be identified by yellow spots that will eventually turn necrotic (Moorman, 2011). Like the previously mentioned viruses, TSV and TSWV will also lead to stunting of plants.

The goal of this study was to evaluate the growth, yield, bloom timing, and quality of *Dahlia* 'Café au Lait' in response to five nitrogen application rates (0, 56, 1112, 168, 224 N kg ha^{-1}) across a three-year field trial. Production timing, yield, and profitability were also tested among six grower participants across Northern Utah.

Materials and Methods

This study was conducted at the Utah Agricultural Experiment Station Greenville Research Farm, located in North Logan, Utah (41.76648°, -111.8105°, elevation 1443 m) from 2019 to 2021. The USDA Plant Hardiness Zone is 5b (USDA, 2021), the mean last frost date is 14 May (Beddes, 2018), and the soil type is a Millville silt loam with 2 % organic matter (USDA-NRCS, 2021). Thirty plots (each 0.61 x 1.8 m) were established in a complete randomized design across three beds (each 0.61 x 18.0 m) that were spaced 1.2 m apart. Each bed had two rows that were 0.6 m apart, with dahlias staggered 0.46 m apart in-row, for seven dahlias per plot and a total of 210 plants in the field. Five treatments included the following nitrogen fertilizer application rates: 0 (control), 56, 112, 168, and 224 kg N ha^{-1}, with six replicates per treatment randomly assigned throughout the plots.

The soil was sampled twice per year to determine phosphorus (P) and potassium (K) rates, as well as nitrogen removal and soil quality. Spring sampling occurred on 13 May 2019, 11 May 2020, and 3 May 2021, which was before tillage to inform annual phosphorus (P) and potassium (K) application rates. Fall sampling occurred on 28 September 2019, 15 October 2020, and 01 October 2021, which was after the growing season had ended, but within a month of first frost and before late-fall and winter precipitation seasons began. Three subsamples were collected per plot at depths of 0.00-0.30 m and 0.30-0.60 m. Subsamples were then combined into one composite per depth per plot for a total of 60 samples per season, dried at 60 °C, ground, and analyzed by the Utah State University Analytical Laboratory in North Logan, Utah (USUAL, 2022). Surface samples were tested for pH, salinity, nitrate-N (Nitrate-N 2 KCl extract method), soil test P and K (Olsen P and K method), while subsurface composites were tested for Nitrate-N (Sheldrick and Wang, 1993; Knepel, 2003; Rhoades, 1982; Olsen and Sommers,1982).

After spring soil sampling each May, the soil was tilled two weeks prior to planting, with a second tillage within one week prior to planting to incorporate fertilizer and create a uniform surface for planting. N was applied as a split application using a urea fertilizer (46-0-0), with half applied within a week prior to planting and half applied one week prior to bloom. P and K were applied according to soil test recommendations prior to planting using triple super phosphate (0-45-0) and muriate of potash (0-0-60). Preplant applications of N, P, and K were broadcast and tilled on 21 May 2019, 23 May

2020, and 17 May 2021. The second N application was applied by banding in the center of the rows on 18 July 2019, 12 August 2020, and 23 July 2021.

Dahlia ‘Café au Lait’ was planted in the last week of May each year, after the last frost date. Rooted cuttings were planted 2019 and 2021, while tubers were used in 2020. Two rows of Toro Aqua-Traxxdrip irrigation were installed at planting and spaced 0.3 m apart. In 2019-2020, the plants were irrigated with low-flow drip irrigation (0.34 liters minute^{-1} 30 m^{-1}) for one to three hours per day, three days per week, based on estimated plant and environmental demand (i.e. 124 to 165 mm per week). In 2021, the plants were irrigated for one hour, three to four times per week (i.e. 162 to 216 mm per week) with high flow drip irrigation (5.07 liters minute^{-1} 30 m^{-1}). Watermark moisture sensors were installed 0.2, 0.3, 0.45, and 0.6 m to monitor soil moisture content and inform irrigation rates.

Flowers were considered ready for harvest when the center of the bloom had just begun to open, at which point the stem was cut at the first node. Per local industry feedback, 150 mm was the minimum stem length for wholesale markets. Shorter stems, which can be used in specialty arrangements, such as arbors, were also graded as marketable when the blooms were undamaged and otherwise high quality. The bloom diameter and stem length were measured to the nearest mm for each marketable stem. Because of the branching habit of dahlias, marketable stems on branches with lower quality or late blooms were counted as a single marketable stem and the less-desirable blooms were graded as culls. Visible factors, such as insect or storm damage, and stem lengths shorter than 150 mm also resulted in cull grades. After harvest, wet weight of each marketable stem was recorded to the nearest g, blooms were dried at 140 °C, and %

dry matter was quantified. Harvest ended with first frost each year, approximately the first to second week of October. The tubers were then dug and washed, after which the length, width, and number of tubers per plant were recorded. Data was analyzed by the PROC GLM function of SAS/STAT 15.1 (SAS Institute; Cary, NC). A significance of 0.05 was defined to determine any significance from the nitrogen application rates, and the LSMEANS Tukey-Kramer adjustment was used to determine any significant differences between each nitrogen rate.

Plant tissue analysis for N was conducted in 2021, using sampling methods based on recommendations for chrysanthemums, another Asteraceae crop (Bohm and Stuessy, 2001). Samples were collected on 19 and 27 July to assess plant nutrient levels before and after the second nitrogen application. Samples were collected by application rate on the first sample date, with 21 leaves randomly collected among each nitrogen rate. The samples were collected per plot for the second sampling, with three leaves taken from each plant in a plot, based on recommendations from Spectrum Analytic Inc. (2009) and Flynn et al. (1999).

By mid-2019, significant viral symptoms were observed, and routine virus testing was coordinated with the Utah State University Plant Pathology Laboratory to identify any viruses that may be present. Three strains of dahlia mosaic virus (DMV), tobacco streak virus (TSV), tomato spotted wilt virus (TSWV), and Impatiens necrotic spot virus (INSV) were monitored. To test for the three DMV strains, total DNA was extracted from one leaf per plant using the Qiagen DNeasy Plant Mini kit. Separate PCR reactions were set up for each strain using strain specific primers (Pahalawatta et al. 2007). The PCR reactions consisted of 12.5 microliter HP Phusion master mix, 1.25 microliter of each primer (100pmol/microliter), 1 microliter of DNA extract and 9 microliters of nuclease-free water for a total of 25 microliters. The resulting PCR products were visualized on a 1% agarose gel stained with ethidium bromide. To test for TSWV, INSV, and TSV, antibody-based ELISA kits (Agdia) were used following manufacturer's instructions. Infected plants were designated with ribbons and observed, with culling occurring by late August.

A three-year grower participant study was conducted across Utah. Six producers across Cache, Box Elder, Weber, Salt Lake, and Juab Counties participated. Each grew ten 'Café au Lait' plants supplied by USU each year from 2019 to 2021. Growers planted in the same location each year. Management decisions (e.g., planting date, nutrient application rates, irrigation scheduling), yield, and pricing were recorded by each grower. The soil at each site was sampled from 0 to 0.30 m and 0.30 to 0.60 m at the beginning (i.e. prior to planting) and end (i.e. after first frost) of each year and analyzed with the research farm trial samples.

A partial budget was quantified to assess the efficiency of nitrogen rates. The set costs including equipment, labor, and transport were adapted from cut flower budgets for field peony and snapdragon (Lewis et al., 2021; Lewis et al., 2021; Lewis et al., 2020). Wholesale pricing of marketable stems was estimated at $4.50 per stem, based on feedback from our grower participants and a local farmer co-operative for wholesale markets.

Results

In 2019, the 168 kg N ha^{-1} application rate produced the most stems per plant, with a mean (±SE) of 2.5 (±1.4) marketable stems per plant and 7.7 (±2.62) culls per plant (Figure 4.1). Yields were lowest in the control, which produced a mean of 0.5 (± 0.2) marketable stems per plant and 1.5 (± 0.4) culls per plant. The 112 kg N ha^{-1} application produced the marketable stems in 2020 at 3.1 (±1.4) stems per plant, while the 224 kg N ha^{-1} application produced the most culls at 4.9 (±1.6) stems per plant. The control and 168 kg N ha^{-1} application rates were the lowest producing in 2020, with 1 (±0.3) and 0.8 (±0.3) marketable stems per plant followed by 2.9 (±1.3) and 3.2 (±0.7) culls per plant. The 168 and 224 kg N ha^{-1} treatments produced similar yields in 2021, with respective means of 7.2 (±1.5) and 7.4 (±0.5) marketable stems per plant, and 3.7 (±0.7) and 3.9 (±0.5) culls per plant. The control was the least productive among all application rates for 2021, with 2.0 (±0.3) marketable stems per plant and 1.0 (±0.3) culls per plant. For 2019 and 2020, there were no significant differences for the marketable or total yield among all application rates. In 2021, the 168 and 224 kg N ha^{-1} rates showed significant differences compared to the control in both marketable and total yield ($p<0.05$), while the 224 kg N ha^{-1} rate displayed a significant difference from the 56 kg N ha^{-1} in total yield ($p<0.05$). 49% of plants either died or were severely symptomatic in 2019, 46% either died or were severely symptomatic in 2020, and 0% died or were severely symptomatic in 2021. Plants fertilized at 0, 56, and 112 kg N ha^{-1} rates produced negative returns of \$78.43, \$37.00, and \$20.00 per m^2. Plants with the 168 and 224 kg N ha^{-1} application rates produced positive returns of \$18.73 and \$18.30 per m^2.

First bloom occurred on 30 July 2019, 11 August 2020, and 27 July 2021. By 0, 56 kg 112, 168, and 224 kg N ha^{-1} application rates, the mean duration until first bloom was 91, 94, 93, 87, and 94 days after planting, respectively, in 2019; 137, 126, 132, 125, and 120 days, respectively, in 2020; and 114, 112, 107, 105, and 104 days, respectively, in 2021. The dates at which 20, 50, and 80% of the total cumulative harvest (T20, T50, and T80, respectively) followed similar trends. The application rate that reached T20 the earliest was the control in 2019, 224 kg N ha^{-1} in 2020, and 168 kg N ha^{-1} in 2021. The application rate that reached T50 the earliest was the control in 2019; 224 kg N ha^{-1} in 2020; and 112, 168, and 224 kg N ha^{-1} rates in 2021. T80 first occurred in the 224 kg N ha^{-1} application in 2020, while it occurred on the same date for all application rates in 2019 and 2021 (Figure 4.2).

Across all three years, differences in marketable stem lengths were insignificant, ($p>0.05$), though there were some trends. Mean marketable stem lengths ranged from 20 (± 2.0) to 21 (± 2.3) cm across all application rates in 2019, with the minimum mean length occurring in the 224 kg N ha^{-1} application rate and the maximum with the 112 kg N ha^{-1} application rate. In 2020, the mean marketable stem lengths ranged from 18 (± 1.4) to 23(± 7.4) cm, with the minimum mean from 112 kg N ha^{-1} application and the maximum from the 224 kg N ha^{-1} application. The range of mean stem lengths was 17 (± 1.7) to 19 (±1.8) cm in 2021, with the minimum present in the control and the maximum present in the 168 kg N ha^{-1} application.

Similar to mean stem lengths, there were no significant differences in bloom diameter by N rate in any of the study years. Mean bloom diameters ranged 15 (± 1.2) to 17 (± 1.4) cm in 2019, with the minimum diameter from the 56 kg N ha^{-1} application and the maximum from the 224 kg N ha^{-1} application. In 2020, the mean bloom diameter range was 14 (± 0.84) to 18 (±5 .3) cm, with the minimum from the 56 kg N ha^{-1} application rate and the maximum from the 224 kg N ha^{-1} application. The mean bloom diameter range was 15 (±0.44) to 17 (±2.4) cm in 2021, with minimum from the 224 kg N ha^{-1} application rate and the maximum from the 56 kg N ha^{-1} application rate.

The mean tuber weights ranged from 0.2 (±0.2) to 0.3 (± 0.2) kg in 2020, the minimum weight occurred in the control, and the maximum tuber weight occurred in the 224 kg N ha^{-1} application rate. The range across the application rates was 0.2 (± 0.1) to 0.4 (± 0.1) kg in 2021, with the minimum weight present in the control and the maximum present in the 224 kg N ha^{-1} application rate. The mean number of tubers per plant ranged from 4 (± 3) to 6 (± 5) in 2020, while the range in 2021 was 3 (± 0.7) to 4 (± 0.7) tubers per plant. In both years, the minimum number of tubers occurred in the control while the maximum occurred in the 224 kg N ha^{-1} application rate.

The nitrogen content of leaf tissue after the second nitrogen application ranged from 2.9 to 3.5%, with the minimum and maximum concentrations from the control and 224 kg N ha^{-1} application rates, respectively. The mean (±SD) soil test values for the UAES Greenville Farm and the grower participant study are given (Table 4.1). Primary macronutrient levels did not exceed optimal rates at the UAES Greenville Farm, while the mean macronutrient concentrations with on-farm participants were high to excessively high at each sampling time, especially soil test phosphorus, which was at excessive levels every year. Mean soil salinity levels were low throughout the duration of the study on the research farm field trial, while the mean grower participant values were near or above the 2 dS m^{-1} threshold for most vegetable and ornamental crops. Mean soil pH values ranged from 7.4 to 8.0 across both studies and little variability occurred across three years.

Discussion

Fertilizer application rates of 168 and 224 kg N ha^{-1} resulted in the greatest marketable and total yields when virus incidence was managed. In 2019 and 2020, the 168 and 112 kg N ha^{-1} applications were the most productive, but overall plant mortality was higher in both years compared to 2021. The 168 and 224 kg N ha^{-1} rates produced similar yields in 2021, which was the only year with significant differences between any of the application rates. The 168 and 224 kg N ha^{-1} rates were significantly greater than the control in both marketable and total yield, while the 224 kg N ha^{-1} rate was significantly greater than the 56 kg N ha^{-1} application in total yield. The yields from the 168 and 224 kg N ha^{-1} application rates in this trial highlight the importance of testing greater rates, as previous research recommended lower rates but rates above 100 kg N ha^{-1} were untested and typically only one rate was compared to an unfertilized control (Prasad et al., 2018; Barik, 2017; Gani et al., 2007).

Greater N application rates did not delay flowering compared to the lower rates, as the 168 and 224 kg N ha^{-1} applications began to bloom at the same time or before the lower N application rates in 2020 and 2021. While the tested maximum application rates were not as high, previous research also supports that added nitrogen does not delay flowering compared to lower rates (Barik, 2017; Prasad et al., 2018). Data from 2021 suggests that increasing nitrogen application rates may lead to a more developed storage organ system, but more research on the subject is needed due to the limited tuber data from plant losses in 2019 and 2020. However, additional nitrogen has been found to increase the mass of potato tubers, which have similar storage and uptake mechanisms to dahlia as tuberous crops (De la Morena et al. 1994).

Through the analysis of a partial budget, the 168 kg N ha^{-1} application was the most economically efficient among all application rates, as the lower three application rates resulted in low yields that produced negative returns. The 224 kg N ha^{-1} rate produced positive returns by increasing yield, hence receipts, but also decreased returns compared to the 168 kg N ha^{-1} rate by increasing fertilizer input costs without a significant increase in yield. The dahlia returns are extremely competitive compared to high-value vegetable crops such as red peppers, which produce returns of \$3.03 m^{2} (Drost and Ward, 2019). Returns from dahlia in Utah are comparable to other cut flowers such as snapdragons, which can produce returns of \$25.70 per m^{2} (Lewis et al., 2021).

Soil test values from the UAES Greenville farm trial were low, especially when compared to the results from the grower participant trials. Soil nitrogen remained especially low throughout the study, and there was little variability between spring- versus fall-sampled values (i.e. samples collected before any fertilizer application in the spring and up to a month after the final harvest in the fall). In Florida, soil nitrogen uptake by potatoes with a fertilizer rate of 225 kg N ha^{-1} was studied across three split applications on a sandy soil (Rens et al., 2016). This resulted in an initial soil nitrogen increase after the fertilizer applications, particularly after the first application, but soil nitrogen levels were near that of an unfertilized soil by the time of harvest (Rens et al., 2016). This was attributed to nitrogen losses through precipitation and soil type. While Northern Utah is semi-arid climate with minimal precipitation during the frost-free growing season, some losses may have occurred through leaching due to irrigation, as dahlias require high irrigation rates for optimal growth. The inefficient root structure of the plant may also contribute to this. In Georgia, three nitrogen rates were tested on onion, which also has a primitive root structure, on a sandy soil at levels defined as low, medium, and high, which corresponded to 146, 224, and 302 kg N ha^{-1} (Díaz-Pérez et al., 2003). These rates demonstrate the need for greater nitrogen rates for crops with primitive root structures.

The soil test results from the grower participant study demonstrate the need for continued public outreach and extension. The mean soil test phosphorous and potassium concentrations were high across all three years, and phosphorus concentrations, specifically, were excessively high. The overapplication of macronutrients leads to unneeded input costs, and depending on the form of fertilizer used, can also lead to a heightened risk for runoff pollution and elevated soil salinity (Pant et al., 2012). The results from 2021 indicate this, as the mean salinity value was above the 2 dS m^{-1} for most garden and ornamental crops, while the maximum salinity value was above the 4 dS m^{-1} threshold for saline soils. Grower participant yield was also the lowest in 2021, which suggests that soil salinity could have inhibited plant growth and bloom production, as many cut flower and ornamental plants can be adversely affected by salinity levels over 2 dS m^{-1} (García-Capparós and Lao, 2018).

Virus infection was a key challenge throughout the study. Visual symptoms, plant mortality, and confirmed virus infection were more prevalent in 2019 and 2020 than 2021. Approximately half of the plants, which were acquired from conventional industry sources, died or were severely symptomatic in 2019 and 2020, while none were in 2021 because certified virus-free stock was used. This highlights the critical need to source virus-free stock and conduct outreach to bring awareness to the importance of virus-prevalence in the dahlia industry. As infected plants are grown, increases in virus incidence can be reduced or prevented by managing disease vectors, such as aphids, thrips, and weeds (Brunt, 1971; Fry, 2012). Though research is ongoing regarding transmission through harvest equipment, such as plant shears, best practices include frequent sanitization to help prevent virus spread (Hosack and Miller, 2017). After virus symptoms are identified, culling plants to prevent further virus spread is needed, though growers are less inclined to do this. The cuttings used in 2019 were sourced from a smaller-scale supplier, while the tubers used in 2020 were sourced from a large company that occasionally performed field scouting of the stock. The cuttings used in 2021 came from certified virus-free stock, but the cuttings themselves were not guaranteed to arrive virus-free. This demonstrates the need for further virus research and outreach, as the stock from which our cuttings and tubers came from in 2019 and 2020 may not have been properly scouted or identified for viral symptoms.

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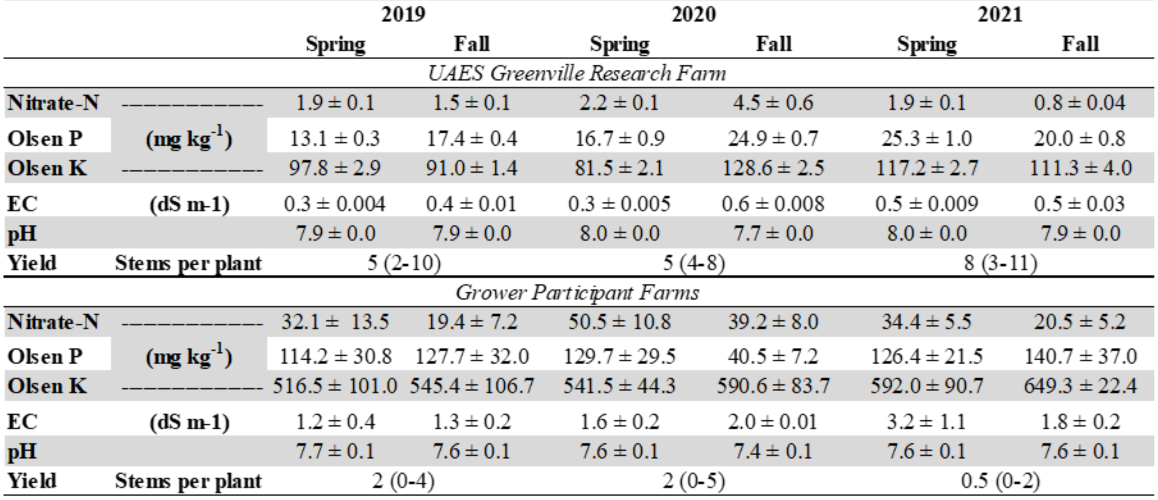
Table 4.1: Mean (±SD) soil test nitrogen (N), phosphorus (P), and potassium (K) in mg kg^{-1}, salinity (EC, in dS m^{-1}), and pH values for the Utah Agricultural Experiment Station Greenville field trial in North Logan, Utah, along with grower participant data in spring and fall for 2019 to 2021 study years.



		2019		2020		2021	
		Spring	**Fall**	**Spring**	**Fall**	**Spring**	**Fall**
UAES Greenville Research Farm							
Nitrate-N	------------	1.9 ± 0.1	1.5 ± 0.1	2.2 ± 0.1	4.5 ± 0.6	1.9 ± 0.1	0.8 ± 0.04
Olsen P	**(mg kg^{-1})**	13.1 ± 0.3	17.4 ± 0.4	16.7 ± 0.9	24.9 ± 0.7	25.3 ± 1.0	20.0 ± 0.8
Olsen K	------------	97.8 ± 2.9	91.0 ± 1.4	81.5 ± 2.1	128.6 ± 2.5	117.2 ± 2.7	111.3 ± 4.0
EC	**(dS m-1)**	0.3 ± 0.004	0.4 ± 0.01	0.3 ± 0.005	0.6 ± 0.008	0.5 ± 0.009	0.5 ± 0.03
pH		7.9 ± 0.0	7.9 ± 0.0	8.0 ± 0.0	7.7 ± 0.0	8.0 ± 0.0	7.9 ± 0.0
Yield	**Stems per plant**	5 (2-10)		5 (4-8)		8 (3-11)	
Grower Participant Farms							
Nitrate-N	------------	32.1 ± 13.5	19.4 ± 7.2	50.5 ± 10.8	39.2 ± 8.0	34.4 ± 5.5	20.5 ± 5.2
Olsen P	**(mg kg^{-1})**	114.2 ± 30.8	127.7 ± 32.0	129.7 ± 29.5	40.5 ± 7.2	126.4 ± 21.5	140.7 ± 37.0
Olsen K	------------	516.5 ± 101.0	545.4 ± 106.7	541.5 ± 44.3	590.6 ± 83.7	592.0 ± 90.7	649.3 ± 22.4
EC	**(dS m-1)**	1.2 ± 0.4	1.3 ± 0.2	1.6 ± 0.2	2.0 ± 0.01	3.2 ± 1.1	1.8 ± 0.2
pH		7.7 ± 0.1	7.6 ± 0.1	7.6 ± 0.1	7.4 ± 0.1	7.6 ± 0.1	7.6 ± 0.1
Yield	**Stems per plant**	2 (0-4)		2 (0-5)		0.5 (0-2)	

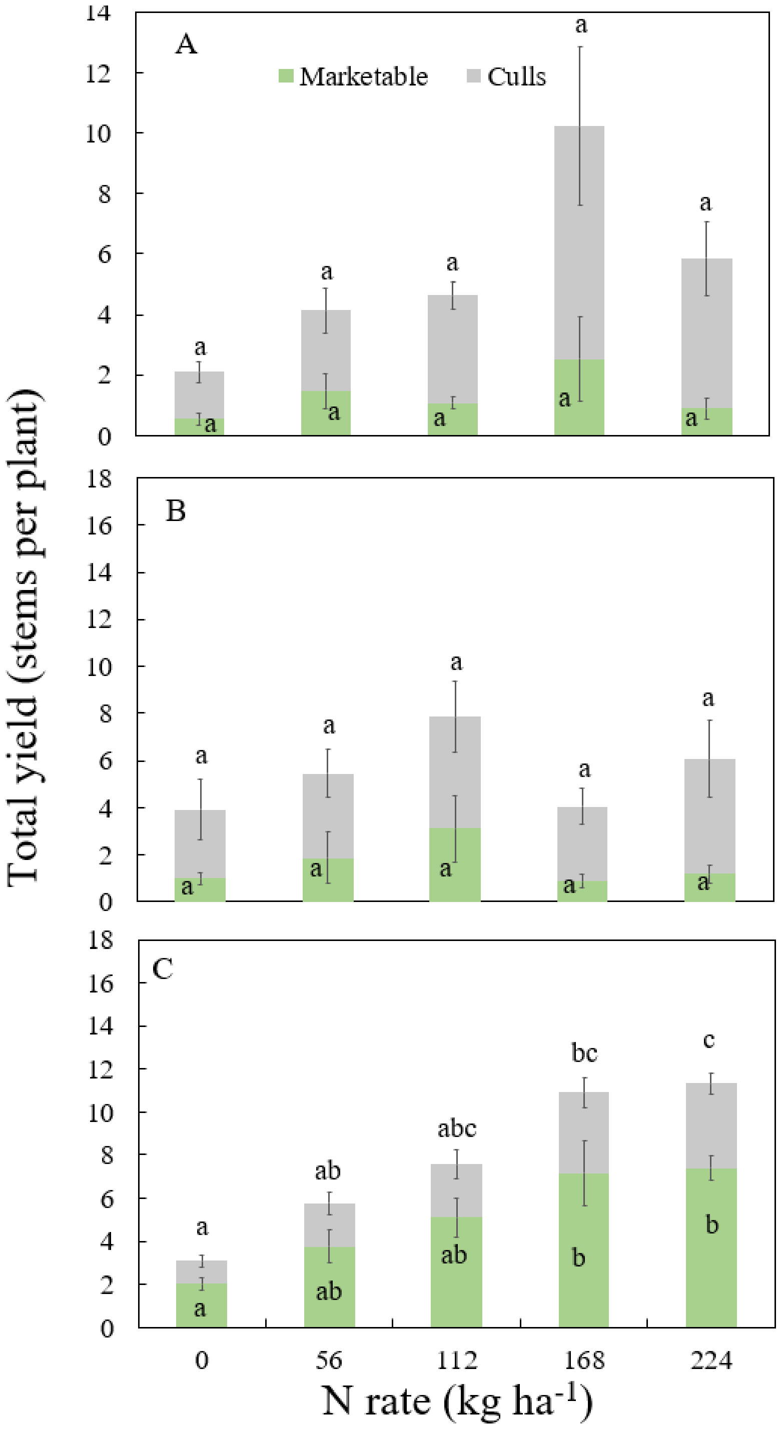


Figure 4.1: Mean (±SE) yield as total stems per plant by nitrogen (N) fertilizer rate of 0, 56, 112, 168, and 224 kg ha^{-1} and growing year in A) 2019, B) 2020, and C) 2021.

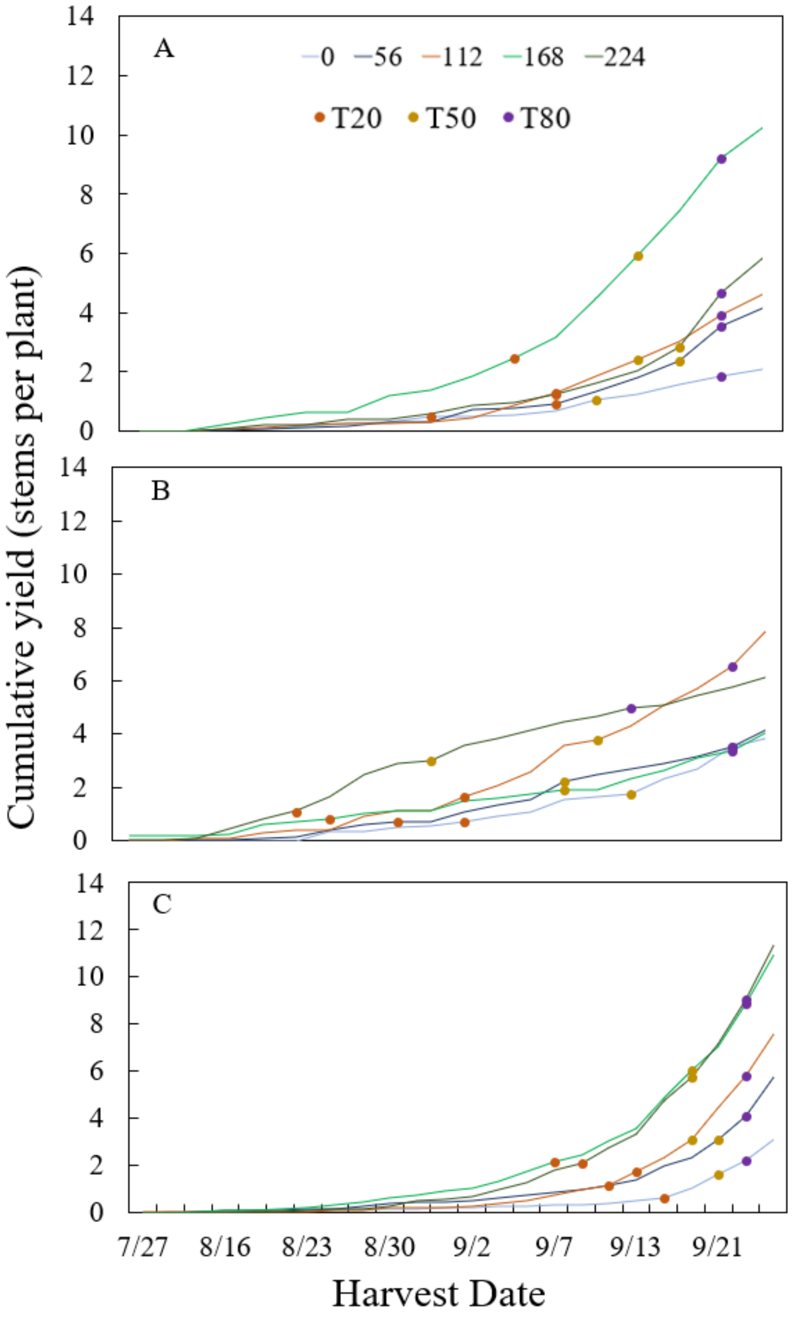


Figure 4.2: Total cumulative yield for each nitrogen rate across each growing season in A) 2019, B) 2020, and C) 2021. T20, T50, and T80 indicate 20%, 50% and 80% of the final cumulative total.

CHAPTER V

CONCLUSION

Urban agriculture has become prevalent in Utah, as there are an estimated 39 community gardens in the Salt Lake County alone, and 105 cut flower microfarms, most of which have been established in the last five years. Urban farmer and community gardens are commonly constricted by land access and space, so it is important that they have the tools and information necessary to maximize yields and net returns. Urban areas are also often at risk for soil contamination due to the higher population and traffic densities along with the presence of current or former industrial sites, so the screening of these soils is vital to minimize and ensure that producers are aware of any contamination risk that might be present.

Overall trace element concentrations were elevated above natural background levels, but mean concentrations were not necessarily hazardous. All arsenic concentrations were above the EPA RSL of 0.68 mg kg^{-1} and Igeo values indicated that the sites were uncontaminated to moderately contaminated for arsenic. The federal screening level is impractical for actual site management and demonstrates a need for state screening levels in Utah that account for natural regional background levels and measured concentrations. Measured lead concentrations ranged from uncontaminated to moderately contaminated, and all urban garden and farm sites except for one were below the EPA RSL of 400 mg kg^{-1}. Ten of 12 sites were below the detectable limits for benzo (A) pyrene and two were above the EPA RSL of 0.11 mg kg^{-1}. Common risk factors were vehicle traffic, lead paint, and located within 5 km of an EPA NPL site. Correlation between the dual traffic score was weak for lead and benzo (A) pyrene, while the correlation was moderate for arsenic. The absence of strong correlation and concentrations above EPA RSLs indicate that urban farms and gardens sampled along the Wasatch Front were not at elevated risk for soil contamination, and that the contaminants present were likely a result of multiple sources throughout the Salt Lake City area.

Because urban soils often have elevated trace element concentrations, it is important to always employ best management practices, even if the soil may not be at hazardous levels that are above a federal or state screening level. In areas with moderate contamination, root crops in leafy greens should be avoided, as they have the most contact with the soil and are often the highest bioaccumulators of contaminants. Inedible crops, such as cut flowers and other ornamental plants, can also be grown on sites with moderate contamination, as there would be reduced contact with the soil compared to other crops and no risk of eating contaminated food. However, if soils are found to be hazardous and above well-established screening levels, it is important to contact either a state or federal agency for guidance, as the bare contact with soil in such sites can pose a significant risk to human health.

Elevated macronutrient levels were observed through an urban soil survey of the Wasatch Front in Utah from 2020 to 2021. The mean concentrations of all three primary macronutrients were above the recommended levels for horticultural crops in Utah, with soil test phosphorus over three times that of local Cooperative Extension guidelines. Overapplication of soil amendments, particularly manure and compost, can increase input costs, thus reducing net returns, increase risk of contaminant transport, and reduce the long-term sustainability and production of soils through the buildup of salts in the soil.

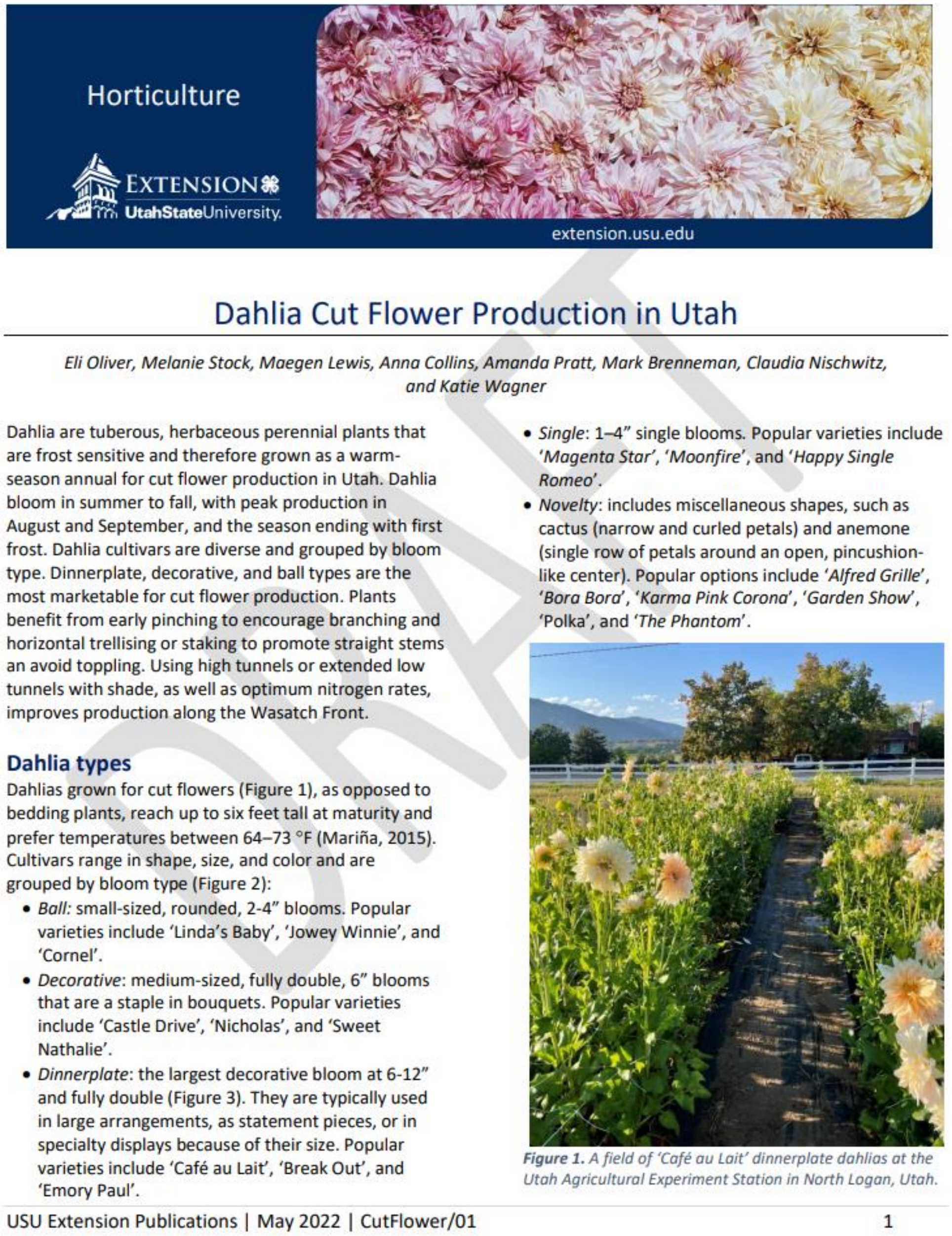
High total carbon supported personal communication with garden leaders and farm managers regarding application of nutrients through the use of composts and manure, which can lead to high or excessive phosphorus levels when applied at rates to meet crop nitrogen or potassium needs. As the mean soil salinity was 2 dS m^{-1} and 22% of sites were greater than 4 dS m^{-1}, guidelines and outreach are needed to bring awareness to amendment use, soil salinity challenges, and the importance of both soil testing and quantifying application rates.

168 kg N ha^{-1} was the most productive and economically efficient application rate in the three-year field trial when virus incidence was heavily managed. Plant mortality rates were high in 2019 and 2020, while all plants survived in 2021, so most conclusions drawn from the study are based upon the data collected from 2021. The 168 and 224 kg N ha^{-1} produced similar yields in 2021, but marginal revenue decreases when the nitrogen rate is increased from 168 to 224 kg ha^{-1}. Higher nitrogen rates did not increase the time to first bloom, while no effects from nitrogen rates were observed in mean stem length or bloom diameter. The weight and number of tubers per plant were highest in the 224 kg N ha^{-1} application in 2021, but more research is needed to draw definite conclusions on nutrient management and tuber production. The lack of significance in 2019 and 2020 demonstrates the effect that virus can have on dahlia survivability and production, and growers should be aware of basic visual virus symptoms in order to respond quickly and minimize overall virus damages. Nutrient overapplication was also problematic in the grower participant trial across the three years of the study, and more extension and outreach is needed to help minimize excess fertilizer applications, which can lead to unneeded costs, pollution through runoff, and the buildup of salt in the soil.

APPENDICES

APPENDIX A.

Draft of USU Extension fact sheet, Dahlia Cut Flower Production in Utah, by E. Oliver, M. Stock, M. Lewis, A. Collins, A. Pratt, M. Brenneman, C. Nischwitz, and K. Wagner. The anticipated submission date for peer review is in May 2022.



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Dahlia Cut Flower Production in Utah

Eli Oliver, Melanie Stock, Maegen Lewis, Anna Collins, Amanda Pratt, Mark Brenneman, Claudia Nischwitz, and Katie Wagner

Dahlia are tuberous, herbaceous perennial plants that are frost sensitive and therefore grown as a warm-season annual for cut flower production in Utah. Dahlia bloom in summer to fall, with peak production in August and September, and the season ending with first frost. Dahlia cultivars are diverse and grouped by bloom type. Dinnerplate, decorative, and ball types are the most marketable for cut flower production. Plants benefit from early pinching to encourage branching and horizontal trellising or staking to promote straight stems an avoid toppling. Using high tunnels or extended low tunnels with shade, as well as optimum nitrogen rates, improves production along the Wasatch Front.

Dahlia types

Dahlias grown for cut flowers (Figure 1), as opposed to bedding plants, reach up to six feet tall at maturity and prefer temperatures between 64–73 °F (Mariña, 2015). Cultivars range in shape, size, and color and are grouped by bloom type (Figure 2):

- *Ball:* small-sized, rounded, 2-4" blooms. Popular varieties include 'Linda's Baby', 'Jowey Winnie', and 'Cornel'.
- *Decorative*: medium-sized, fully double, 6" blooms that are a staple in bouquets. Popular varieties include 'Castle Drive', 'Nicholas', and 'Sweet Nathalie'.
- *Dinnerplate*: the largest decorative bloom at 6-12" and fully double (Figure 3). They are typically used in large arrangements, as statement pieces, or in specialty displays because of their size. Popular varieties include 'Café au Lait', 'Break Out', and 'Emory Paul'.
- *Single*: 1–4" single blooms. Popular varieties include '*Magenta Star*', '*Moonfire*', and '*Happy Single Romeo*'.
- *Novelty*: includes miscellaneous shapes, such as cactus (narrow and curled petals) and anemone (single row of petals around an open, pincushion-like center). Popular options include '*Alfred Grille*', '*Bora Bora*', '*Karma Pink Corona*', '*Garden Show*', 'Polka', and '*The Phantom*'.

Figure 1. *A field of 'Café au Lait' dinnerplate dahlias at the Utah Agricultural Experiment Station in North Logan, Utah.*

Dinnerplate *Ball and Pompon*

Single *Decorative* *Novelty - Cactus*

Figure 2. *Examples of dahlia bloom types.*

Plant stock options

Dahlias can be planted as plugs from seed, tubers, or rooted cuttings. Growing dahlias from seed is less common because the seeds are not true to type; the blooms vary in shape and color. Most dahlias from seed produce single blooms and thinner stems that are less marketable than cultivars from tubers or cuttings. Tubers and cuttings both produce clones of the mother plant, and therefore the bloom forms and color are more predictable. They also produce more robust and marketable stems, particularly for wholesale.

Germination

Growing dahlia from seed require temperatures between 70 - 80 °F for optimal germination and growth. Starting seeds indoors 8 weeks before the last frost is recommended to improve the emergence rate and give the plants a jumpstart on the season. Seeds should be sown ¼" deep in a size 72-cell tray. Germination occurs within 7 to 21 days under optimal temperatures. Temperatures cooler than 60 °F can lengthen germination time and decrease germination rates. Seed-grown dahlias should be given 16 hours of supplemental light and can be fertilized at 3 to 4 weeks. Harden off seedlings and transplant them outside once the danger of frost has passed.

Site Preparation

For optimal growth, dahlias require well-drained soil. Soil should be tilled to incorporate fertilizer or compost based on routine soil test recommendations. A soil nutrient test is recommended in new planting areas or where soil testing has not occurred in 1-2 years. USU's analytical laboratory performs soil tests with pricing and information available on their website. Tilled soil should be raked smooth. Install drip irrigation and plastic mulch, if desired, before planting dahlias.
For dahlia grown in a high tunnel, begin planning and preparation during the previous fall by installing the plastic high tunnel covering prior to heavy rain or snowfall. This will ensure the soil will be the right moisture level for workability early the following spring and decrease the risk of disease.

Planting, Spacing, and Pinching

Dahlias are a warm-season crops that are intolerant of freezing conditions. In high tunnels, dahlia can be planted 4-6 weeks before the average last frost date, while field-grown dahlias are planted after the last frost date, particularly if using cuttings or plugs. To find the average last frost date for your area, visit the USU Climate Center website.

Space dahlias 12-18" apart, with more space given to larger varieties, such dinnerplate types. Dahlia tubers should be planted four to six inches deep, ideally when soil temperatures reach 60 °F. Because tubers are planted several inches below ground, thus protected from fluctuating air temperatures, they may be planted up to 1-2 weeks prior to last frost. Cuttings must be planted after the danger of frost has passed. Plant cuttings deep enough to bury the first set of leaves to provide stability for the growing plant and ensure strong root contact with the soil. If temperatures dip near freezing after planting, use row cover to protect from freezing conditions. Pinch plants when they are 12" tall to promote branching. To pinch, remove the terminal bud by cutting the stem at the next node (Figure 4). Pinching can slightly delay initial bloom, but increases the total yield of marketable stems.

Figure 3. *Dinnerplate dahlias produce the largest blooms. Pictured: 'KA's Cloud'.*

Irrigation

Dahlias require consistent irrigation, and larger varieties have greater water needs. Maintaining evenly moist soil is critical for timely production. Though many sources warn against overwatering, in Utah, this is less of a concern than underwatering and the soil becoming too dry. Here, our semi-arid conditions naturally result in less moisture in the soil profile and greater evapotranspiration rates. Aim for moist conditions, but not saturated.

Drip irrigation is ideal, as it keeps moisture off the foliage and blossoms, and conserves water. Drip lines can be spaced 8-12 inches apart and positioned near the base of the plants in the row. Apply 2-4" of water per week, depending on temperature, growth stage, and soil texture. Early spring plantings with little root growth initially require less water that is more frequently applied to maintain moisture near the soil surface. As vegetative growth increases, plants are flowering, and tubers are bulking, irrigate less often, but deeply. An example of irrigation at maturity with a high-flow drip system includes irrigating every other day for one hour (rates of 1.34 gal/min per 100 ft), for a total of 3-4 irrigation events per week.

Figure 4. *The terminal bud was pinched (yellow arrow) when this plant was 12" tall.*

Fertilizer

Dahlias have higher requirements for nitrogen and moderate requirements for phosphorous and potassium compared to other cut flower crops. In general, 0.3 – 0.4 lbs of nitrogen should be added per 100 square feet *each year*. For example, a total of 0.4 pounds (1 cup) of conventional urea fertilizer (46-0-0), or 2 pounds (about 2.5 cups) of organic 16-0-0 fertilizer. One application option is to apply half of the nitrogen before or at planting and side-dress the other half about eight weeks after planting, just prior to bloom. Alternatively, nitrogen may be applied through a weekly fertigation schedule that begins after planting and ends prior to bloom. For example, dissolvingApplications of phosphorous and potassium should be added before or at planting, but should only be applied based on a soil test, as these nutrients can build up in the soil. USU's Calculating Fertilizer for Small Areas is a useful tool for calculating applications.

Trellising

Providing support for the plants through staking, caging, or horizontal trellis is required to promote straight, marketable stems and keep plants from toppling. Dahlia stems are gravitropic, meaning stems will curve upwards if they begin to bend. The stems are also hollow and susceptible to breakage. Installing stakes every three feet on each side of the bed and use baling twine to corral the plants is an efficient method. At USU, using two levels of mesh trellis (6" x 6") pulled taut across the bed has been most effective (Figure 5). To stake the trellis, install wooden stakes or tall rebar at 3- to 5-foot intervals along the bed (Figure 5). If shading or low tunnels will be used, the supportive hoops can be used to pull the trellis taut across the row and avoid the need for additional stakes (see Rauter for more information). Horizontal trellis is easiest to install before planting and can also serve as a planting grid. As the plants grow, move the trellis upwards. By maturity, position the first level of trellis at a 12" height and the second level of trellising at 24–30". Trellis added after planting, and particularly when plants are taller, is cumbersome and can damage stems.

Figure 5. Dahlia with the first layer of horizontal trellis at a 12" height. As plants grow, a second layer at 24-30" will be added to prevent toppling and encourage straight stems.

Shade

Shade trials for dahlia production in Utah are underway and early results indicate shade may provide cooling and protect against intense afternoon sunlight. For high tunnel production, plastic should be removed by June and replaced with 30% shade cover until September. In counties that are in USDA Hardiness Zones 6-7 and warmer, shade may also increase field production by improving establishment of cuttings, hastening plant growth and the onset of flowering, and encouraging longer stems. Using extended low tunnel arches is an effective method for installing shade cloth in the field. Attach shade cloth to the south side and top of the arches for beds oriented east-west, or to the west side and top when beds are oriented north-south (Figure 6). Low tunnels will need to be extended for proper clearance with mature plants. For more information on low tunnel extensions, shading, and other uses for cut flower production, read our fact sheet, Low Tunnels for Cut Flower Production.

Figure 6. *Dahlia oriented east-west at Wheeler Historic Farm in Murray, Utah. This allows for shade to be attached to only the south side and top of the low tunnel for more wind flow and efficient harvests.*

Harvest and Storage

Dahlias typically begin flowering at eight weeks after planting, with dinnerplates taking the longest to initiate bloom. Harvest during the cool parts of the day when the center of the blooms has just begun to open (Figure 7). Harvesting prior to this stage will result in an incomplete opening of the bud and a shorter vase life, while harvesting after this stage results in potential wilting and also reduces vase life. Harvest or deadhead all the blooms to maintain flowering. Florist-grade stems should be a minimum of 6-10" long with a preferred length of 12" or greater for dinnerplates and decoratives. Place the cut stems directly into water while harvesting to avoid wilting. Securing chicken wire across the openings of buckets allows for stems to be placed in water without the blooms falling in and becoming wet. After harvest, strip leaves, trim the ends, and place in warm water with floral preservative. For most dahlias, a vase life of 3-7 days is expected if proper harvest procedures are followed and the stems are stored in cool conditions. Larger bloom types, such as dinnerplate varieties, tend to have shorter vase lives than smaller bloom types.

Bud forming.

Bud beginning to expand.

Outer petals expanded, but center of the bloom is closed.

Perfectly formed and ready for harvest.

Optimal harvest stage has passed.

Deformed bloom that is not marketable.

Figure 7*. The stages of flower opening, including the optimal stage to harvest, with 'Café au Lait' as an*

For non-diseased plants, tubers can be stored over winter and replanted in spring. After first frost and before the soil freezes, the above-ground vegetation dies back and the tubers can be dug up for storage. After digging, allow the tubers to cure for 1-2 days to reduce the risk of disease, then store in media, such as vermiculite or peat, to preserve moisture. Ideal storage conditions are dark and cool, but above 50 °F. Growers along the southern extent of the Wasatch Front may choose to heavily mulch the soil with hay, straw, or leaves, and leave the tubers in the ground. This practice risks losing tubers in the event of a cold winter, prohibits the grower from splitting the crowns to increase the number of plants next year, but saves labor time in digging and space for storage.

Economics

Dahlia are highly-sought, local flowers due to their showy and unique blossoms, transport limitations, popular colors, and strong stems. Wholesale dahlias are easily damaged during shipping and storage. Therefore, high-quality, locally grown dahlias that are longer than 6 to 10" and a popular color are in strong demand.

Dahlias, particularly dinnerplates, are sold by the stem, not bunched. The wholesale price for dinnerplate dahlias ranges from $3.50-$5.00 per stem. USU trial dahlias sold for $4.00 per stem in the Cache Valley and Wasatch Front markets in 2020.

Dahlia disease

Dahlias are susceptible to viral diseases, which can be common across sources of plant stock. Finding certified virus-free stock is highly recommended, as infected plants cannot be treated and should be isolated or removed to prevent disease spread to other crops. Table 1 details the common diseases that can be found in dahlias and control options. It is important to follow best management practices, such as the sanitization of harvest equipment and control of common pests (Table 2).

TABLE 1. COMMON DISEASES OF DAHLIA.

Disease	Identification	Control
ROOT, STEM, AND CROWN ROTS	Fungi that infect roots and crowns of plants. Dull-colored foliage or wilting followed by yellowing of plants. Plants may be stunted and then eventually die. Roots are dark, soft, or decayed.	Avoid excessive irrigation/moisture. Plant in well-drained soil. Dig out and destroy infected plants.
POWDERY MILDEW	A fungal disease that produces a white or light gray powder on leaves, stems, and occasionally flowers.	Spray with copper fungicide. Cut down, remove and destroy all stems of the plant after fall freezes. Keep the area weeded and debris free. Early season infestations should be controlled. If late in the season, chemical control may not be warranted.
RUST	Brown/orange-colored spots on the underside of foliage.	Rogue plants that have fungus to prevent spread.
DAHLIA MOSAIC VIRUS (DMV)	DNA virus that is primarily identified by a chlorosis mosaic pattern on leaves. Can also lead to necrosis, stunting, and reduced yield. Commonly spread by aphids that have fed on other infected plants.	Sanitize any pruning/harvesting equipment and control aphids to reduce spread of DMV.
CUCUMBER MOSAIC VIRUS (CMV)	Disease associated with stunting of plants along with mosaic patterns and yellow spots on leaves. Can be spread by aphids and the use of contaminated equipment.	Control of aphids is important in managing CMV, as is the sanitation of any pruning/harvesting equipment. The removal of weeds can also reduce the spread of CMV, and plants should be thrown out if confirmed to have CMV.
IMPATIENS NECROTIC SPOT VIRUS (INSV)	Viral disease with many symptoms including stunting of plant, yellowing of leaves,	Control of thrips is vital in reducing spread of INSV. Keep plants suspected of virus in a separate location from healthy plants, and dispose of any plants that are confirmed to carry INSV.

	and necrotic spots on leaves. Can be spread by thrips.	
Tobacco Streak Virus (TSV)	Viral disease which can lead to chlorosis and necrotic streaking on leaves. Mosaic patterns may also be present. Virus will lead to stunting of plants. Can be spread by thrips.	Sanitation of equipment is an important method of preventing disease spread. Control of thrips can also help to reduce spread of TSV.
Tomato Spotted Wilt Virus (TSWV)	Viral disease that has a wide host range. It causes yellow ringspots on leaves that can turn brown/black. Spread by thrips, a common insect pest.	Prevent infection by purchasing clean plant material, eliminating weeds (hosts) from the area, and immediately removing infected plants. Chemical control of thrips (Table 2) may be warranted, but is difficult.

Table 2. Pests of Dahlia.

Insect	Identification	Control
Aphids	Green, yellow, or black; soft-bodied; sap-sucking insect. Populations can build up very rapidly. Sticky honeydew from the aphids can accumulate on leaves and stems.	Encourage natural predators by avoiding broad-spectrum insecticides. Ladybeetle releases inside a high tunnel can be effective, but will leave the area over time. Minute Pirate Bugs and Lacewings are also effective. Applying insecticidal soaps and oils is the best choice for most situations.
Earwigs	Omnivorous pest that can feed on aphids and other small pests. Detrimental to ornamental plants as they will also chew on petals and young leaves.	Earwig traps are an effective means of control. A jar or plastic container can be filled with soy sauce and vegetable oil, then capped with holes punched in the lid. Bury the container up to the lid. Earwigs will be attracted to the soy sauce, and the oil will prevent the earwigs from leaving the trap. Empty and replace periodically.
Grasshoppers	Feed on leaves and flowers of snapdragon later in the season. Cause ornamental damage.	Apply bait and sprays early in life cycle (late May/early June). Carbaryl, acephate, and Nosema locustae are effective. Hand-removal and exclusion are the best options for adults, as chemical control is difficult.
Two-spotted Spider Mites	Very small (0.02"), feed primarily on the underside of leaves and cause stippling (light dots) on the leaves that turn bronze then brown and fall off (Figure 5). Sometimes confused for leaf burn. Form webbing that covers leaves.	Provide adequate irrigation to avoid stress. Control surrounding weeds. Keep dust to a minimum (avoid rototilling between rows) as dust increases mite activity. Avoid/limit broad-spectrum insecticide treatments as mite outbreaks often follow. Spray plants with water, insecticidal oils, or soaps. Releasing generalist beneficial insects, such as Minute Pirate Bugs, can also help control populations.
Western flower Thrips	Very small insect with fringed wings that does not directly damage snapdragons, but transmits viruses and hides in florets, making blooms undesirable for florist use.	Chemical control is difficult, Malathion only protects for 2 days and will kill beneficial insects. Keep weeds (often host plants) clear of the area. Spinosad can be effective but is toxic to natural enemies and bees. Releasing generalist beneficial insects, such as Minute Pirate Bugs, can also help control populations.

USU Dahlia Trials

In 2019–21, trials were conducted at Greenville Research Farm in North Logan, UT (USDA Hardiness Zone 5) and at Wheeler Historic Farm in 2021 (USDA Hardiness Zone 7). In North Logan, nitrogen (N) rates for dinnerplate dahlias with 'Café au Lait'. Rates ranged from no additional N (0 lb per 100 ft2) to high rates of 0.5 lb N per 100 ft2). A second trial in North Logan tested high tunnel production was compared to open field conditions with decorative and dinnerplate varieties that were planted in April in high tunnels and late-May in unprotected fields. High tunnels were covered with plastic until late-June, at which time it was removed and replaced with 30% shade cloth. At Wheeler Historic Farm, the use of white versus black plastic and shade versus no shade with low tunnels were tested in 2021.

Nitrogen Rate Evaluation

Plant growth rates were greater with N application rates of 100 lb N per acre or more. Harvest began on July 27, and the most total and marketable blooms were harvested from plants fertilized at 150 lb N per acre. We expect the field trial to continue through the end of September and look forward to our growers' findings.

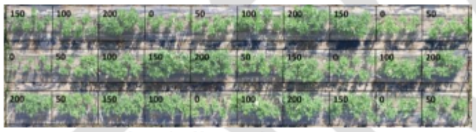


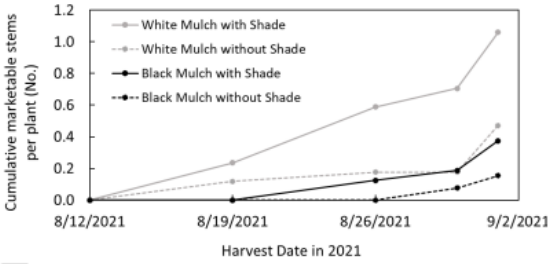
Figure X. *Field of 210 'Café au Lait' plants that are divided into 30 plots that each test one of five N treatments: 0, 50, 100, 150, and 200 lb N per acre.*

Use of plastic mulch and shade

Overall, the use of 30 % shade improved plant establishment, which was challenging with the late planting dates and the record heat and drought conditions in Utah during 2021. Black plastic without shade resulted in a loss of 17 % of plants, while black plastic with shade resulted in an 11 % loss of plants.

Figure X. The cumulative number of stems from 'Serena' and 'White Pearl' harvested from the high tunnel (green lines) and field (black lines). The solid lines represent total stems (marketable quality + cull), while the dashed lines are only marketable stems.

With the use of white plastic, plant loss was only 6 % with or without shade. Harvest of marketable stems began one week earlier with plants grown in white plastic mulch (August 19) compared to black plastic mulch (August 26), regardless of shading treatment (Figure 2). Though harvest has just begun, plants with white plastic mulch and shade have been more productive (Figure 2). We hypothesize the white plastic mulch and shade may have kept conditions cooler and the solar radiation less intense, leading to improved early growth and production. We are eager to continue monitoring production into October and compare total yields with soil temperature data, as well as repeat this study in 2022.



High tunnel vs. field production

The high tunnel advanced harvest by 35 days, with first harvest occurring on July 9 in the high tunnel, and August 13 in the field (Figure 1). As of August 27, the high tunnel produced an average of ten stems per plant while the field has averaged six (Figure 1). Quality has also been greater with high tunnel production. The minimum standard for marketability with Utah florists is six inches and undamaged blooms. The high tunnel has averaged five marketable stems per plant as of August 27, the average stem length was 11 inches, with stems lengths ranging from 8 to 34 inches. In the field, harvest has only occurred on two dates, with the first marketable stems harvested on August 27. On average, the field has produced one marketable stem per plant

(Figure 1), indicating the benefit of high tunnels in Northern Utah.

High tunnels allow for more control of the planting environment. Extremely wet or cold spring conditions can postpone field plantings and further delay field production compared to high tunnels. Suboptimal weather conditions in one year of our trials (2019) resulted in an 8-week delay in field production with 42% lower marketability. This indicates the importance of early field plantings for this cool season crop and highlights the year-to-year consistency high tunnels provide.

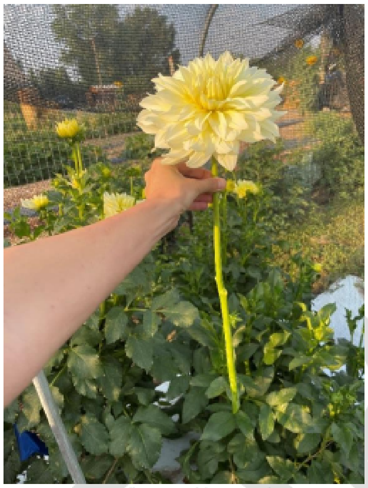


Figure X. A 23.5" stem of 'La Luna' dinnerplate dahlia that was harvested from a plant with white plastic mulch and shade cloth from a low tunnel.

Conclusions

Dahlias are a high demand flower that come in a wide variety of size and color. They are highly sensitive to freezing conditions, and larger varieties must be supported in some way when the plant begins to reach a height of two feet. Dahlias can be affected by a wide range of diseases and pests, and care should be taken to sanitize equipment when dealing with suspected viral plants in order to reduce any viruses that may be present. While fertilizer trials are still ongoing, it appears that dahlias benefit most from nitrogen rates above 100 lbs per acre. The use of white mulch and shade seems to reduce plant temperatures and improve production, and high tunnels can be employed to lengthen the growing season and provide a more controlled environment compared to the field.

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Disclaimers

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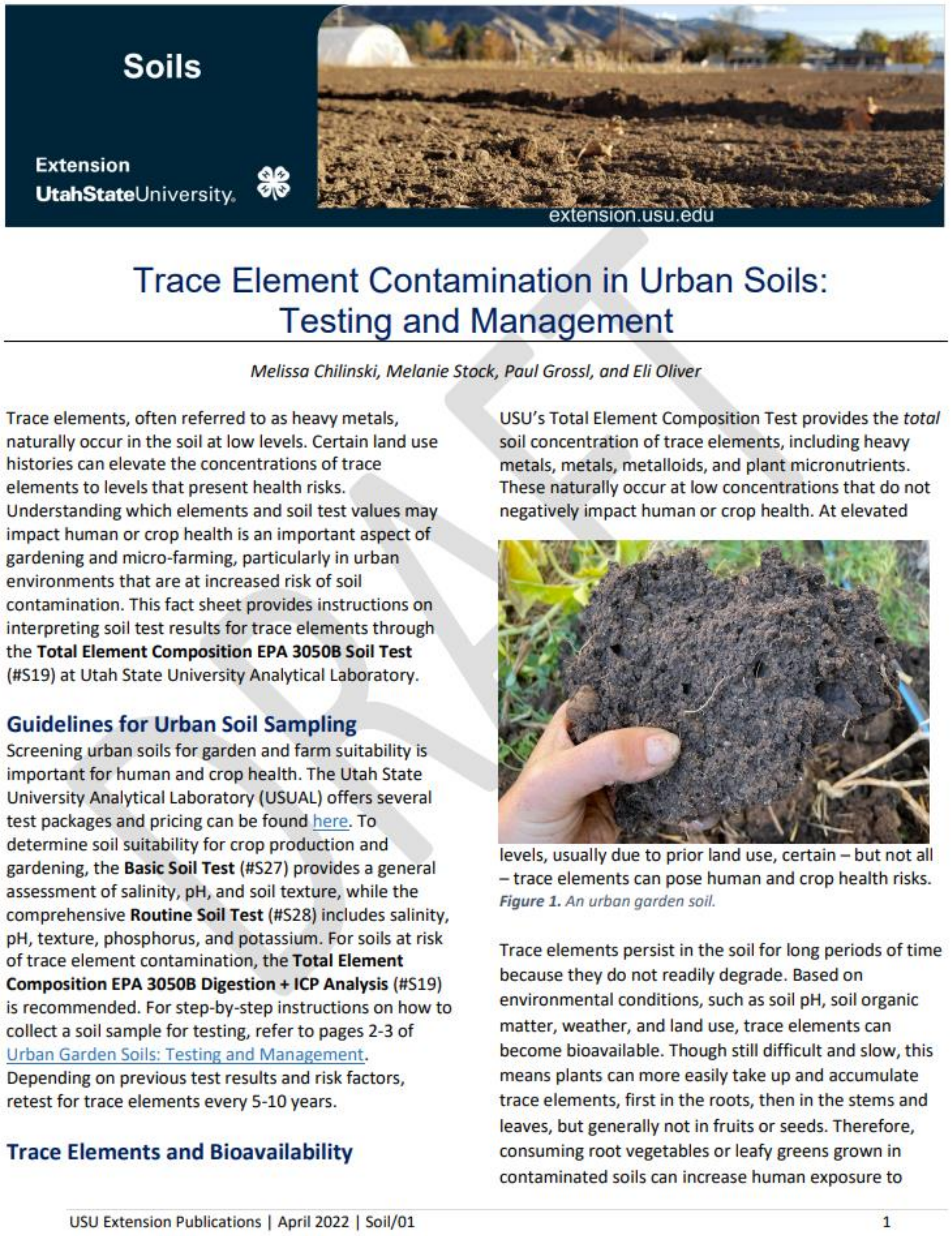
APPENDIX B.

Draft of USU Extension fact sheet, Trace element contamination in urban soils: testing and management, by M. Chelinski, M. Stock, P. Grossl, and E. Oliver. This fact sheet was submitted for per review, accepted, and in final editing. The anticipated publication date is in May 2022.



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Trace Element Contamination in Urban Soils: Testing and Management

Melissa Chilinski, Melanie Stock, Paul Grossl, and Eli Oliver

Trace elements, often referred to as heavy metals, naturally occur in the soil at low levels. Certain land use histories can elevate the concentrations of trace elements to levels that present health risks. Understanding which elements and soil test values may impact human or crop health is an important aspect of gardening and micro-farming, particularly in urban environments that are at increased risk of soil contamination. This fact sheet provides instructions on interpreting soil test results for trace elements through the **Total Element Composition EPA 3050B Soil Test** (#S19) at Utah State University Analytical Laboratory.

Guidelines for Urban Soil Sampling

Screening urban soils for garden and farm suitability is important for human and crop health. The Utah State University Analytical Laboratory (USUAL) offers several test packages and pricing can be found here. To determine soil suitability for crop production and gardening, the **Basic Soil Test** (#S27) provides a general assessment of salinity, pH, and soil texture, while the comprehensive **Routine Soil Test** (#S28) includes salinity, pH, texture, phosphorus, and potassium. For soils at risk of trace element contamination, the **Total Element Composition EPA 3050B Digestion + ICP Analysis** (#S19) is recommended. For step-by-step instructions on how to collect a soil sample for testing, refer to pages 2-3 of Urban Garden Soils: Testing and Management. Depending on previous test results and risk factors, retest for trace elements every 5-10 years.

Trace Elements and Bioavailability

USU's Total Element Composition Test provides the *total* soil concentration of trace elements, including heavy metals, metals, metalloids, and plant micronutrients. These naturally occur at low concentrations that do not negatively impact human or crop health. At elevated levels, usually due to prior land use, certain – but not all – trace elements can pose human and crop health risks.

Figure 1. *An urban garden soil.*

Trace elements persist in the soil for long periods of time because they do not readily degrade. Based on environmental conditions, such as soil pH, soil organic matter, weather, and land use, trace elements can become bioavailable. Though still difficult and slow, this means plants can more easily take up and accumulate trace elements, first in the roots, then in the stems and leaves, but generally not in fruits or seeds. Therefore, consuming root vegetables or leafy greens grown in contaminated soils can increase human exposure to

trace element contaminants. Consuming fruit (e.g. tomatoes, peppers, apples) or seed (e.g. corn, beans) crops pose the least risk and are considered safer.

Table 1. Land histories that can elevate risk of soil contaminants. Adapted from Urban Garden Soils: Testing and Management.

Property History or Feature	**Reason for Potential Soil Contamination**
Home built before 1978	Soil surrounding the house could have elevated lead levels from lead-based paint chips, particularly older homes with siding.
Parked cars/vehicles	Leakage of oil, gasoline, or other chemicals.
Proximity to a highway	Trace element pollution from traffic road dust and roadside soils. Traffic density and vehicle speed increase risk. Contamination can occur up to 150 ft away from roads, but greatest risk is within 30 ft.
On an old orchard	Soil could have elevated lead and arsenic levels because lead arsenate was a common pesticide used from 1892 through the 1940s (banned in 1988).
Proximity to industrial facilities (refinery, smelter, construction site, mine, plant)	Soil could have elevated levels of contaminants from deposition, improper waste disposal, and/or previous mismanagement of leaks and spills.
Structures with pressure- treated wood built before 2004	Until 2004, pressure-treated wood was preserved with Chromated Copper Arsenate (CCA) for residential use.

Bioavailable contaminants can also be toxic to plants (known as phytotoxicity) by inhibiting the plant's ability to absorb essential nutrients from the soil. This results in delayed or decreased germination, stunting, reduced yield, and other adverse effects.

Contaminant forms that are not bioavailable can also pose a risk to human health. Primary exposure occurs through direct contact with bare soils, such as through digging, planting, playing, or eating unwashed vegetables. Root crops present the greatest risk for exposure if not washed and/or peeled correctly.

Common Contamination Sources

Low levels of trace elements naturally occur in the soil, but they can become elevated with previous land use histories and by location, particularly in urban environments. Testing soils for trace elements is highly recommended if common risk factors are identified on the property (Table 1), the property has an unknown history, and/or food crops will be grown.

Screening Levels

The US EPA set Regional Screening Levels **(RSL)** to standardize human health exposure limits for trace elements. RSLs relevant to urban farming and gardening are found under 'Resident Soil' and include an exposure limit in mg/kg, or equivalent units of ppm. Subsequently, some states have **State Guidance Levels (SGL)**. States may set their own levels because regional differences like soil composition (pH, texture, presence of other elements), climate, and land use affect the behavior of contaminants. Utah often refers to California SGLs because of the similar climate, soil, and farm practices.

Total Element Composition Test Results

USUAL offers the **Total Element Composition EPA 3050B Digestion + ICP Analysis Soil Test** (#S19) that gives the *total* soil concentrations of 22 naturally occurring trace elements as % or mg/kg (EPA, 1996). An example of a soil test report is given in Figure 2. If there is not a result for an element, the value was below the lab's detection limit (i.e. the concentration was very low). 10 of the 22 elements in the report are particularly important, as they may be harmful to human health or inhibit crop growth at high concentrations. These include Arsenic (As), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Lead (Pb), Manganese (Mn), Nickel (Ni), Selenium (Se), and Zinc (Zn) and are the focus of this fact sheet. The other 12 elements do not pose a risk at any levels, thus are not included in this fact sheet.

Arsenic (As)

Arsenic is a common carcinogen and not a plant nutrient. It is often found at elevated levels in the soil. Long and short-term exposures to As can result in acute and chronic adverse health effects. Common sources of elevated As in soils include past use of lead arsenate pesticides, CCA pressure-treated lumber, mining, and coal ash. Suggested exposure limits vary from RSLs and SGLs. Based on regional background levels, precautions are recommended at soil test concentrations that are 12 ppm and above in Utah.

Cadmium (Cd)

Cadmium is a carcinogen and not a plant nutrient. It naturally occurs in soils from geological weathering and volcanic eruptions. Elevated soil levels of Cd are primarily caused by human practices like steel manufacturing, coal and incinerator emissions, and production of some phosphate fertilizers. Cadmium is more often in a bioavailable form and can accumulate in plant tissue, which accounts for the majority of total intake exposure (Amjad et al., 2017).

Chromium (Cr)

Chromium can be a carcinogen and is not a plant nutrient. Elevated soil levels of Cd are primarily caused by CCA-treated lumber, steel and textile manufacturing, or paint and pigment spills. There are several forms of Cr; Cr (III) is the most common and Cr (VI) is most toxic, but quickly degrades into Cr (III). Generally, Cr (III) binds tightly to clays and organic matter across all pH levels, thereby reducing bioavailability, hence health risks. Cr (VI) is carcinogenic and more mobile, although unlikely to be present unless a direct spill occurred that temporarily increased soil concentrations. *Note:* RSLs and the Total Element Composition Test results are for total Cr, reflecting that Cr (VI) quickly degrades into Cr (III), which accounts for much of total Cr.

Cobalt (Co)

Cobalt is a potential carcinogen and is not a plant nutrient, although it may have a beneficial role in plant development at low levels (<15 to 25 ppm) (Hu et al., 2021). Elevated soil levels of Co are usually caused by mining, fertilizer production, or sewage waste. Risk of plant uptake increases with lower soil pH (soil acidity) and the form of Co present. Soil in Utah generally has a higher pH, which reduces human health risk from Co, however, it can be phytotoxic.

Copper (Cu)

Copper is not a carcinogen, is low risk to human health unless levels are excessive (>3,100 ppm), and is an essential plant micronutrient. Cu is widely used in organic pesticides and fungicides, as well as found in CCA-treated lumber, industrial waste, and municipal wastewater. Risk of plant uptake is very low, unless soil pH is less than 5.5, which is rare in Utah. Soil levels of Cu that are well below the human health threshold value for risk (e.g. 75-100 ppm) can be phytotoxic.

Lead (Pb)

Lead is a common carcinogen that can be harmful to human health and is not a plant nutrient. It is especially hazardous to children and can cause permanent cognitive defects and high blood pressure and pregnancy challenges in adults. Elevated soil levels of Pb are usually caused by past use of lead paint, leaded gasoline deposition, and wind deposition of leaded dust or soil. Most risk of exposure comes from direct contact (e.g. digging, planting, playing, ingesting) with bare, contaminated soil. Pb is not bioavailable unless soil levels are high, organic matter content is low, and/or pH levels are <5.0 or >7.5. In these cases, lead can bioaccumulate in plant tissue, particularly in leafy greens and root crops.

Manganese (Mn)

Manganese is not a carcinogen and is an essential plant micronutrient. Elevated soil levels can be caused by industrial emissions, steel production, and combustion. Generally, Mn binds tightly to clays and organic matter at soil pH up to 8, making health risks less common in Utah. Although Mn is an essential micronutrient, excessive concentrations in plant tissue can result in phytotoxicity, such as chlorosis and a reduced photosynthetic rate (Millaleo et al., 2010).

Nickel (Ni)

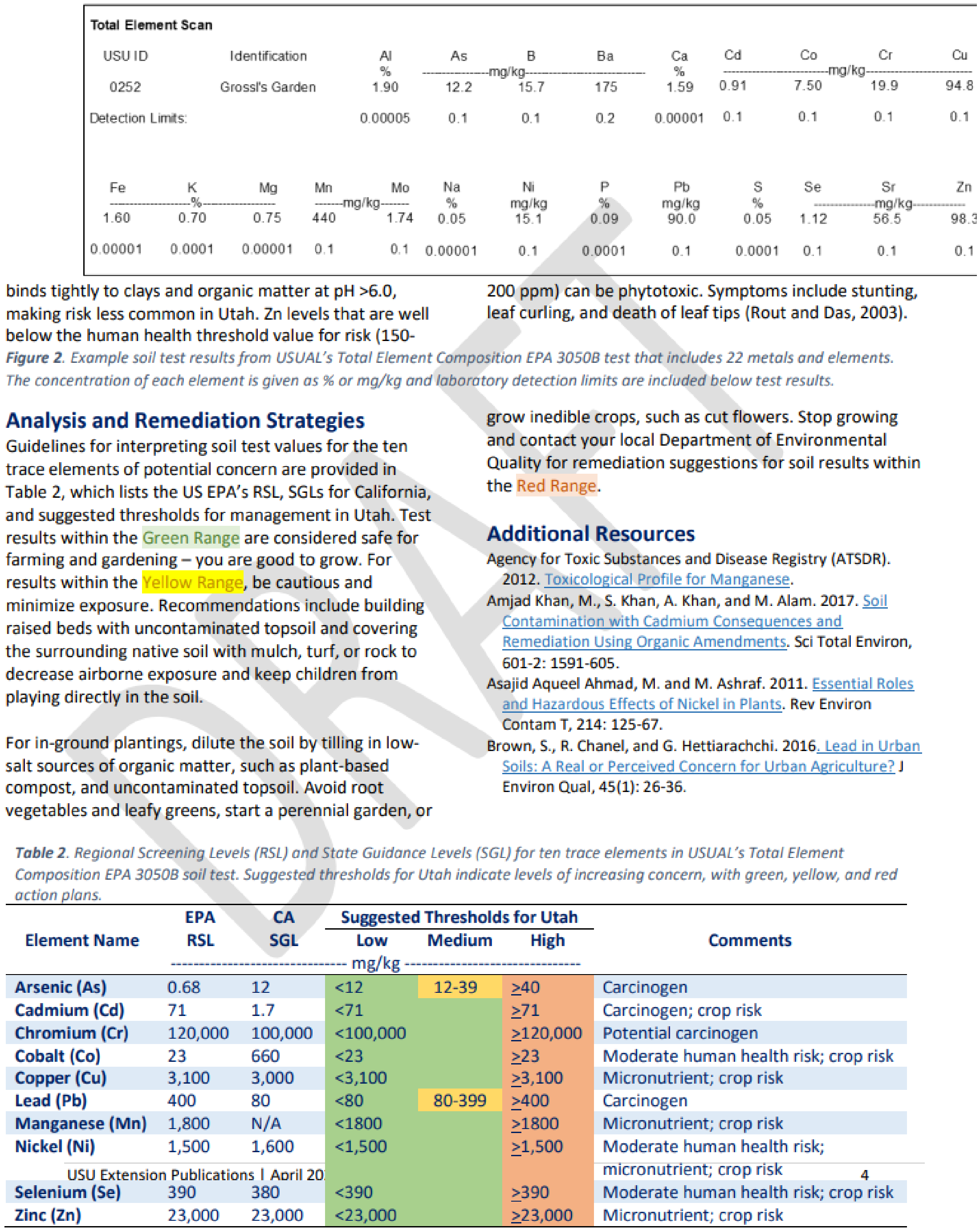
Nickel is not a carcinogen, but poses moderate risk to human health at elevated levels (>1,500 ppm), and is an essential plant micronutrient. Elevated soil levels are usually caused by metal manufacturing, incinerator and fossil fuel emissions, and sewage sludge. Ni bioavailability, hence health risk, increases at soil pH >7.5, which is a common in Utah, but is low at pH 5.5 to 7.5. Soil levels of Ni that are well below the human health threshold value for risk (40-60 ppm) can be phytotoxic (Asajid and Ashraf, 2011).

Selenium (Se)

Selenium is not a carcinogen or a plant nutrient, but elevated levels (>390 ppm) can pose short-term and long-term human health effects. Elevated soil levels are usually caused by industrial processes like glass, ceramics, and pharmaceutical production, as well as from coal deposition. At soil levels below the human health threshold value for risk (e.g. 100 ppm), Se can inhibit plant nutrient uptake and disrupt physiological and biochemical processes (Hasanuzzaman et al., 2020).

Zinc (Zn)

Zinc is not a carcinogen and is an essential plant micronutrient. Elevated soil levels are usually caused by mine tailings, steel product manufacturing, wood preservatives, and industrial wastewater. Generally, Zn



Total Element Scan

USU ID	Identification	Al %	As mg/kg	B mg/kg	Ba mg/kg	Ca %	Cd mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg
0252	Grossl's Garden	1.90	12.2	15.7	175	1.59	0.91	7.50	19.9	94.8
Detection Limits:		0.00005	0.1	0.1	0.2	0.00001	0.1	0.1	0.1	0.1

Fe %	K %	Mg %	Mn mg/kg	Mo mg/kg	Na %	Ni mg/kg	P %	Pb mg/kg	S %	Se mg/kg	Sr mg/kg	Zn mg/kg
1.60	0.70	0.75	440	1.74	0.05	15.1	0.09	90.0	0.05	1.12	56.5	98.3
0.00001	0.0001	0.00001	0.1	0.1	0.00001	0.1	0.0001	0.1	0.0001	0.1	0.1	0.1

binds tightly to clays and organic matter at pH >6.0, making risk less common in Utah. Zn levels that are well below the human health threshold value for risk (150-200 ppm) can be phytotoxic. Symptoms include stunting, leaf curling, and death of leaf tips (Rout and Das, 2003).

***Figure 2**. Example soil test results from USUAL's Total Element Composition EPA 3050B test that includes 22 metals and elements. The concentration of each element is given as % or mg/kg and laboratory detection limits are included below test results.*

Analysis and Remediation Strategies

Guidelines for interpreting soil test values for the ten trace elements of potential concern are provided in Table 2, which lists the US EPA's RSL, SGLs for California, and suggested thresholds for management in Utah. Test results within the Green Range are considered safe for farming and gardening – you are good to grow. For results within the Yellow Range, be cautious and minimize exposure. Recommendations include building raised beds with uncontaminated topsoil and covering the surrounding native soil with mulch, turf, or rock to decrease airborne exposure and keep children from playing directly in the soil.

For in-ground plantings, dilute the soil by tilling in low-salt sources of organic matter, such as plant-based compost, and uncontaminated topsoil. Avoid root vegetables and leafy greens, start a perennial garden, or grow inedible crops, such as cut flowers. Stop growing and contact your local Department of Environmental Quality for remediation suggestions for soil results within the Red Range.

Additional Resources

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***Table 2**. Regional Screening Levels (RSL) and State Guidance Levels (SGL) for ten trace elements in USUAL's Total Element Composition EPA 3050B soil test. Suggested thresholds for Utah indicate levels of increasing concern, with green, yellow, and red action plans.*

Element Name	EPA RSL	CA SGL	Suggested Thresholds for Utah			Comments
			Low	Medium	High	
	mg/kg					
Arsenic (As)	0.68	12	<12	12-39	≥40	Carcinogen
Cadmium (Cd)	71	1.7	<71		≥71	Carcinogen; crop risk
Chromium (Cr)	120,000	100,000	<100,000		≥120,000	Potential carcinogen
Cobalt (Co)	23	660	<23		≥23	Moderate human health risk; crop risk
Copper (Cu)	3,100	3,000	<3,100		≥3,100	Micronutrient; crop risk
Lead (Pb)	400	80	<80	80-399	≥400	Carcinogen
Manganese (Mn)	1,800	N/A	<1800		≥1800	Micronutrient; crop risk
Nickel (Ni)	1,500	1,600	<1,500		≥1,500	Moderate human health risk; micronutrient; crop risk
Selenium (Se)	390	380	<390		≥390	Moderate human health risk; crop risk
Zinc (Zn)	23,000	23,000	<23,000		≥23,000	Micronutrient; crop risk

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Disclaimers

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