Nitrogen Management and Virus Incidence on Cut Flower Production of Dahlia

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Abstract

Cut flower production, particularly of dahlia, has a strong profit potential for small farms. This study evaluated the field response of dahlia 'Café au Lait' to nitrogen (N) rates and implemented routine testing for common viruses. Yield was measured over a three-year field trial with five N application rates: 0, 56, 112, 168, and 224 kg N·ha^{-1} (0, 50, 100, 150, 200 lb N·A^{-1}) in North Logan, Utah (USDA Hardiness Zones 5). A grower-participant study was also conducted in Northern Utah (USDA Hardiness Zones 5 – 7) to understand cultural practices and challenges. Application of 168 and 224 kg N·ha^{-1} (150 and 200 lb N·A^{-1}) produced the greatest yields of stems per plant, while 168 kg N·ha^{-1} (150 lb N·A^{-1}) was the most economically efficient from partial economic budgets. Viruses were highly prevalent in stock, resulting in cull rates of nearly 50% in 2019 and 2020. After sourcing lab-cultured stock in 2021, 0% of plants were culled, indicating a strong need for management of viruses in dahlia. Soil survey results from the grower-participant study revealed widespread levels of elevated macronutrients and salinity that increased annually and correlated with decreasing yield across farms. This study helps determine optimal N rates, increase awareness of virus management, as well as supporting fertility outreach with small growers to promote soil sustainability.

Species used in this study: Dahlia, *Dahlia pinnata* 'Café au Lait'.

Index words: Café au Lait, fertilizer, nutrient, soil fertility, salinity, infection.

Significance to Horticulture Industry

Across the U.S., locally-grown cut flowers are becoming an economically important crop for small farms. In the U.S. Intermountain West, dahlia is the top specialty cut flower for farmers to grow, as well as the top cut flower sourced by state florists. Demand for dahlias, namely dinnerplate cultivars (i.e., those with a minimum bloom diameter of 15.2 cm (6 in), Stock et al. 2023), however, is much greater than supply, which florists cite as the top barrier to increasing purchases from local farms. However, production of dahlia cut flowers is challenging because of a lack of soil fertility recommendations for dinnerplate dahlias, as well as widespread virus presence. This study determined a rate of 168 kg nitrogen ha^{-1} (150 lb nitrogen·A^{-1}) was the most economically efficient for a dinnerplate variety, while six viruses, including three strains of dahlia mosaic virus (DMV), warranted routine testing. Nutrient management recommendations are presented to avoid over-application, highlight soil sustainability needs for small farms, and identify extensive virus infection effects on production. More research is recommended for other dahlia types, as well as to increase the availability of clean-stock options for growers.

Introduction

The increasing demand for cut flowers has led to a rapid growth of flower farms across the U.S. According to the 2021 Floriculture Crops Summary, the number of growers increased by 10% in top producing states from 2019 to 2021 (a 22% increase from 2020 to 2021), and the domestic wholesale market was valued at $359.8 million for larger farms (i.e., farms with greater than $100,000 in sales) (USDA-NASS 2022, USDA-NASS 2021). Membership in the Association of Specialty Cut Flower Growers (ASCFG), which reflects this national growth for smaller farms, had a membership increase from 1,401 to 2,882 in the last three years (personal communication, Judy Laushman, Executive Director, ASCFG, 8 September 2022). In the U.S. Intermountain West, cut flower micro farms rapidly increased since 2018, particularly in Utah, where 135 farms established, at a rate of approximately 30 new cut flower farms per year (Oliver 2022). The Utah Cut Flower Farm Association (UCFFA), established in 2019, has 170 members that include bordering communities in Idaho and Arizona (personal communication, Britin van Brocklin, Treasurer, UCFFA, 17 March 2023). These growers target specialty cut flowers, prioritizing production types that do not transport well and have a short storage or vase life, for florist wholesale markets and direct-to-consumer sales through farmers markets and community-supported agriculture (Shimizu-Yumoto and Ichimura 2013). For small farms, locally grown cut flowers offer a premium profit potential with minimal land requirements, with net returns of flower crops, such as snapdragons (*Antirrhinum majus* L.) and peonies (*Paeonia lactiflora* Pall.), averaging $27.00 per m^2 (Lewis et al. 2020, Lewis et al. 2021a).

With the current increases in urban farming (Siegner et al. 2018) and cut flower production, particularly in new regions, such as the U.S. Intermountain West, locally adapted growing recommendations are important for optimizing yield. In 2020, 85% of Utah cut flower growers identified a lack of regional guidelines as the main challenge for increasing production (Stock 2020), as the climate, soils, and water vary from conditions in the traditional U.S. production areas for cut flower crops. Dahlias (*Dahlia sp.*) are particularly challenging to produce, yet widely grown, with

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87% of Utah cut flower farms relying on dahlias as a primary summer to fall flower crop (Stock 2020). Dahlias ship poorly and have strong consumer demand, thus commanding premium local market pricing, with wholesale receipts averaging \$4 to \$5 per stem across the Wasatch Front (Stock et al. 2023). Moreover, in a 2021 survey of florists across Utah, 89% listed dahlia as the top crop to source from local farms (Curtis and Stock 2023), highlighting the importance of dahlia to the state and as a niche for local growers.

To optimize regional production, targeting nutrient management, particularly nitrogen (N) application rates, is critical. The American Dahlia Society (2001), based in Indiana, recommends 195 kg $N{\cdot}ha^{-1}$ (174 lb $N{\cdot}A^{-1}$) and stated growers commonly applied two- to three-times more fertilizer than needed, which may reduce yield by as much as 25%. Most fertility research on dahlias has been conducted in humid subtropical regions of Northern India, with greater N rates increasing both yield and quality (Barik 2017, Gani et al. 2007, Gupta et al. 2016, Kumar et al. 2019, Naziki et al. 2017, Prasad et al. 2019, Sheergojri et al. 2013). In a field trial of 0 to 300 kg $N{\cdot}ha^{-1}$ (0 to 267 lb $N{\cdot}A^{-1}$) fertilizer rates with *D. variabilis* 'Giani Zail Singh', yield (in stems per plant) doubled from 4.7 with the 0-application control to 10.1 at the maximum rate of 300 kg $N{\cdot}ha^{-1}$ (267 lb $N{\cdot}A^{-1}$), while bloom diameter increased from 102 to 161 mm (Gupta et al. 2016). Other studies targeted rates between 0 to 100 kg $N{\cdot}ha^{-1}$ (0 to 89 lb $N{\cdot}A^{-1}$) (e.g., Barik 2017, Gani et al. 2007, Kumar et al. 2019, Naziki et al. 2017, Prasad et al. 2019, Sheergojri et al. 2013), and findings suggested greater rates may be needed to determine maximum yield (i.e., the maximum production of marketable stems per plant) and economic optimums (i.e., the maximum return per input fertilizer cost). For example, the mean total yield (stems per plant) of *D. variabilis* 'Kenya Yellow' increased from 2.7 at a 0 kg $N{\cdot}ha^{-1}$ (0 lb $N{\cdot}A^{-1}$) fertilizer rate to 5.7 at 50 kg $N{\cdot}ha^{-1}$ (45 lb $N{\cdot}A^{-1}$), to 8.7 at 80 kg $N{\cdot}ha^{-1}$ (71 lb $N{\cdot}A^{-1}$), while the bloom diameter increased from 150 to 177 to 213 mm at 0, 50, and 80 kg $N{\cdot}ha^{-1}$ (0, 45, and 71 lb $N{\cdot}A^{-1}$), respectively (Gani et al. 2007). Similarly, with *D. variabilis* 'Kenya Orange' and various combinations of synthetic-, manure-, and compost-based N, the mean yield increased from 6.6 stems per plant and a 172 mm bloom diameter at a zero-nutrient rate, to 9.9 stems per plant and a 220 mm bloom diameter with 75 kg $N{\cdot}ha^{-1}$ (67 lb $N{\cdot}A^{-1}$) plus 1.25 t ha^{-1} of vermicompost (N content unknown) (Prasad et. al. 2018). As plant yield and bloom quality increased with each N rate, a strong N response of field dahlia was established. Yet more research is needed to test additional N rates that establish maximum plant yields and economic optimums, particularly in new regions for production with semi-arid and temperate climates.

As a tradeoff with increasing yield, greater N application rates may lengthen the period to bloom due to increased vegetative growth. For 'Kenya Yellow', the timing of first bloom occurred at 76.0 days with an 80 kg $N{\cdot}ha^{-1}$ (71 lb $N{\cdot}A^{-1}$) application rate and 69.3 days with 0 kg $N{\cdot}ha^{-1}$ (0 lb $N{\cdot}A^{-1}$) (Gani et al. 2007), though comparing one N rate to a zero-rate control introduces interactions with plant stress factors (Wada and Takeno 2010). Similarly, a relatively short bloom delay occurred through increasing N rate with *D. variabilis* 'Eternity Sports' at a maximum delay of eight days (Barik et al. 2017) and six days with 'Giani Zail Singh' (Gupta et al. 2016). Conversely, bloom of 'Kenya Orange' advanced by 16 days with increasing total N from a combination of synthetic and manure-based sources (Prasad et al. 2018), with manure N availability likely slowed through mineralization (Ma et al. 1999), thus preventing excessive vegetative growth and flowering delay. Marginal lag to bloom timing generally occurred with increasing N in previous trials, but response to greater N rates in areas with shorter growing seasons must also be considered to establish regionally specific farm recommendations.

With the growth in specialty cut flower farms in the U.S. Intermountain West, where the semi-arid and temperate climate, as well as a short frost-free season, impact crop production, developing regional N rates with a high-demand cultivar on local markets may help farms increase stem yield per plant, hence supply. Therefore, the goal of this study was to evaluate the growth, yield, bloom timing, and quality of *D. pinnata* 'Café au Lait' in response to five N application rates (0, 56, 1112, 168, 224 N kg ha^{-1}) across a three-year field trial in Northern Utah. Production timing, yield, and economic returns were also tested among six grower participants along Utah's Wasatch Front.

Materials and Methods

Field and laboratory operations. This study was conducted at the Utah Agricultural Experiment Station (UAES) Greenville Research Farm in North Logan, Utah (41.76648°, −111.8105°, elevation 1443 m) from 2019 to 2021. The USDA Plant Hardiness Zone is 5b (USDA-ARS 2021), the average frost-free growing season lasts 15 May to 25 September (USU Climate Center 2022), and the soil type is a Millville silt loam with 2% organic matter (USDA-NRCS 2021). Thirty plots (each 0.61 × 1.8 m) were established in a complete randomized design across three beds (each 0.61 × 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 N fertilizer application rates of 0 (control), 56, 112, 168, and 224 kg $N{\cdot}ha^{-1}$ (0, 50, 100, 150, and 200 lb $N{\cdot}A^{-1}$), with six replicates per treatment, were randomly assigned.

The soil was sampled each spring and fall to determine annual phosphorus (P) and potassium (K) rates (Cardon et al. 2008), as well as N removal and soil quality. Three subsamples were collected per plot at depths of 0.00-0.30 m and 0.30-0.60 m and combined into one composite per depth per plot for a total of 60 samples each spring and fall. Surface samples were tested for pH and salinity (Rhoades 1982), particle size (Sheldrick and Wang 1993), nitrate-N (Nitrate-N 2 KCl extract method; Knepel 2003), and soil test P and K (Olsen P and K method; Olsen and Sommers 1982), while subsurface composites were tested for nitrate-N (Knepel 2003). Total soil N was calculated as the sum of the two depths. Within a week of planting, the soil was tilled to incorporate all broadcasted P (triple super phosphate, 0-45-0), K (muriate of potash, 0-0-60), and half of the treatment N (urea, 46-0-0). The other half of the treatment N was banded in within one week prior to bloom (in late July to mid-August). Overall, the soil was largely classified as "low" in both soil-test P (mean of 18.3 ppm ±0.4 SE) and K (mean of 98.8 ppm ±1.4 SE) across plots and years. According to these test results, the soil was generally amended at an annual rate of 183 kg $P_2O_5 \cdot ha^{-1}$ (163 lb $P_2O_5 \cdot A^{-1}$) and 183 kg $K_2O \cdot ha^{-1}$ (163 lb $K_2O \cdot A^{-1}$) (Cardon et al. 2008, Horneck et al. 2011).

Dahlia 'Café au Lait' were planted on 31 May 2019, 15 May 2020, and 24 May 2021, after risk of frost. New stock was purchased each year. Rooted cuttings were sourced in 2019, tubers in 2020, and certified virus-free cuttings in 2021. Two rows of drip irrigation (Toro, Aqua-Traxxdrip, Bloomington, MN) were installed per bed at planting and spaced 0.3 m apart. Based on estimated crop and environmental demand, a total of 124 to 216 mm was applied per week across three to four irrigation events. Soil moisture sensors (Watermark, Irrometer Company, Riverside, CA) were installed 0.2, 0.3, 0.45, and 0.6 m to inform irrigation rates and a weather station located approximately 0.2 km away recorded precipitation, air temperature, and solar radiation (USU Climate Center 2022). Weed barrier fabric (Weed Barrier, 116 g, DeWitt, Sikeston, MO) was used between beds and plots were hand-weeded one to two times per week to suppress weeds. Plant tissue analysis for N was conducted in 2021, using sampling methods based on recommendations for zinnia (*Zinnia elegans* L.), another Asteraceae crop (Ahmad et al. 2012). Samples were collected on 19 and 27 July to assess plant nutrient levels before and after the second N application. One composite sample was collected per application rate on the first sample date, with 21 leaves randomly collected across all replicates for each N rate. For the second sampling, one composite was analyzed per plot, with three leaves collected per plant in every plot, based on recommendations from Spectrum Analytic Inc. (2009) and Flynn et al. (1999).

By August 2019, severe viral symptoms were observed that could reduce dahlia quality and yield. The plants were considered infected through visual identification of symptoms with the Utah State University Plant Pathology Laboratory, with symptoms including chlorotic mosaic and/or streak patterns on the leaves, yellowing patterns not attributed to nutrient deficiency, and stunting (Moorman 2011). Tests for three strains of dahlia mosaic virus (DMV), including D10 (now Endogenous plant pararetroviral sequence, DvEPRS), Holland (now Dahlia common mosaic virus, DCMV), and Portland; Tobacco streak virus (TSV), Tomato spotted wilt virus (TSWV), and Impatiens necrotic spot virus (INSV) were acquired to monitor all plants in the 2020 and 2021 field seasons starting in June of each year. These viruses were considered common, but their general prevalence in new areas of production, such as Utah, was largely unknown. Plants were sampled as soon as viral symptoms were detected, after sufficient growth occurred for tissue sampling. To test for the three DMV strains, total DNA was extracted from one leaf per plant using the Qiagen DNeasy Plant Mini Kit (Qiagen, Germantown, MD). 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 (New England Biolabs, Ipswich, MA), 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, Inc., Elkhart, IN) were used following manufacturer's instructions. Infected plants were designated with ribbons and observed. Those that were severely symptomatic and dead or nearly dead were removed between August 28 to September 3, 2019, and by August 24, 2020. No plants were removed in 2021.

Data collection and analysis. Blooms were harvested when the center began to expand and were graded as marketable or cull per local industry feedback. A minimum stem length of 100 mm was used for local wholesale markets, which included specialty arrangements, such as floral arch designs that use shorter stems. Because of the branching habit of dahlias, marketable stems on branches with lower quality, unopened blooms were counted as a single marketable stem. Stems damaged by insects or weather conditions, or stems shorter than 100 mm (4 in), were graded as culls. For each marketable stem, the bloom diameter and stem length were measured to the nearest mm. In 2020 and 2021, tuber production was assessed by recording the length, width, and number of tubers per plant after washing. The number of days from planting to first bloom and the dates at which 20, 50, and 80% of harvest occurred (T20, T50, and T80, respectively) were also recorded.

Data were analyzed by the PROC GLM function of SAS/STAT 15.1 (SAS Institute; Cary, NC). Statistical significance was defined at 0.05, and the LSMEANS Tukey-Kramer adjustment was used to compare yield and growth response among N rates each year. A partial budget was quantified to assess the economic efficiency of the N rates. The set costs including equipment, labor, and transport were adapted from cut flower budgets for field peony and snapdragon (Lewis et al. 2021a, Lewis et al. 2020). The wholesale pricing of marketable stems was $4.50 per stem, based on feedback from our grower participants and a local farmer co-operative for wholesale markets.

Grower-participant study. A three-year grower participant study was conducted with six dahlia producers across Cache, Box Elder, Weber, Salt Lake, and Juab Counties in Northern Utah. Each farm grew ten 'Café au Lait' plants supplied each year by USU from 2019 to 2021. Growers planted in the same location each year and 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 each spring (i.e., prior to planting) and fall (i.e., after first frost) and analyzed with the research farm trial samples. All of the producers reported multiple applications of two or more nutrient amendments each year, though application rates were not always provided. Overall, the producers reported compost applications each year, with most applying approximately 5 cm (2 inches) of composted chicken manure, horse manure, or municipal sources. Though the guaranteed analyses were unknown,

Table 1. **Mean monthly and seasonal air temperature (C), total monthly and seasonal precipitation (mm), and mean monthly and seasonal totals for solar radiation (MJ m^{-2}) from the months (mo.) of May through October in 2019, 2020, and 2021. Data from the Utah Agricultural Experiment Station - Greenville Research Farm weather station in North Logan, Utah, located approximately 0.2 km from the site field. The 30-year (30-yr) normal levels (1981–2010) for Logan, Utah, are also shown for air temperature and precipitation (Western Regional Climate Center 2022).**

	Air Temperature (C)				Precipitation (mm)				Solar Radiation (MJ·m^{-2})		
Mo.	2019	2020	2021	30-yr	2019	2020	2021	30-yr	2019	2020	2021
May	12.7	14.1	13.4	13.1	21.6	21.3	11.9	60.7	564	741	796
June	17.5	16.9	22.9	18.3	3.0	73.9	0.0	34.5	799	732	906
July	22.7	21.9	25.2	23.2	8.6	3.8	0.8	20.3	806	902	853
Aug	21.9	23.3	20.6	22.6	4.6	3.0	35.1	20.8	762	776	685
Sep	15.6	15.9	16.6	16.7	110	11.9	9.9	38.9	493	596	595
Oct	3.9	9.4	8.6	10.0	14.7	10.4	64.8	51.6	389	424	346
Seasonal	*15.7*	*16.9*	*17.9*	*17.3*	*163*	*125*	*122*	*227*	*3813*	*4170*	*4180*

average nutrient concentrations were 1.4% N-5.8% P_2O_5-2.8% K_2O for composted chicken manure, 0.7% N-0.3% P_2O_5-0.9% K_2O for composted horse manure, and 1.2% N-1.1% P_2O_5-0.7% K_2O for municipal in Utah (Stock et al., 2019). Two to eight applications of fish emulsion (5-1-1, Lilly Miller, Atlanta, Georgia) per year were also common across farms, as well as the incorporation of bloodmeal, homemade teas, and wood-based mulches. Two farms applied urea (46-0-0) and one farm also applied 28-4-16 (Miracle Gro, Marysville, OH). These applications resulted in a range of approximate annual application rates from 50.4 kg N·ha^{-1} (45 lb N·A^{-1}) to 976 kg N·ha^{-1} (871 lb N·A^{-1}).

Results and Discussion

Weather and plant conditions. The growing season (May to October) in 2019 was cooler than the 30-year normal (1981–2010) each month, while the average monthly temperatures were near normal in 2020, and above normal in 2021, particularly in June and July, which were characterized by severe heat and drought in the U.S. Intermountain West (Table 1). As semi-arid climates have strong daily temperature fluctuations, the average daily maximum temperature was warmer than the average daily minimum by 29.0 C in 2019, 30.6 C in 2020, and 27.4 C in 2021. In all years, the growing season had less precipitation than the normal of 227 mm (WRCC 2022), with 2019 as the wettest year in the study at 163 mm, and 2020 and 2021 at nearly 50% less than normal (Table 1). Similarly, solar radiation was greatest in 2021, particularly in May and June, and each year accumulated 3,813 to 4,180 MJ m^{-2} (Table 1), highlighting the intensity of the high-elevation conditions, especially in years with less precipitation.

Virus infection of stock was extensive, as TSWV, TSV, INSV, and the three strains of DMV were identified. In 2019, 49% of plants were severely symptomatic from virus infection and culled, while 46% were in 2020. The laboratory-confirmed incidence of virus in 2020 as a percent of plants per N-rate treatment ranged from 0.0 to 7.1% for TSWV, 0.0 to 2.4% for INSV, 4.8 to 9.5% for TSV, 2.4 to 4.8% for DMV-Holland, and 0.0 to 4.8% for DMV-Portland (Table 2). DMV-D10 was the most prevalent virus that came on the sourced tubers in 2020, with 9.5 to 26.2% of plants infected; the greatest number of infected plants randomly occurred in the 168 kg N·ha^{-1} (150 lb N·A^{-1}) treatment (Table 2). In 2021, certified virus-free stock was sourced and 0% were severely symptomatic or culled. Laboratory-analysis confirmed TSWV, INSV, TSV, and DMV-D10 were not present in 2021, and incidence of DMV-Holland and DMV-Portland ranged from 2.4 to 7.1% of plants per N-rate treatment (Table 2).

Documenting widespread infection in stock from industry sources in 2019 and 2020 highlights the critical need to make virus-free dahlias more available for producers. After

Table 2. **Incidence of laboratory-confirmed virus infection of dahlia 'Café au Lait' as percent (%) of plants per nitrogen (N) application rate in 2020 and 2021 at Utah Agricultural Experiment Station - Greenville Research Farm in North Logan, Utah. Virus testing included Tomato Spotted Wilt Virus (TSWV), Impatiens Necrotic Spot Virus (INSV), Tobacco Streak Virus (TSV), and the three strains of Dahlia Mosaic Virus (DMV): Holland, D10, and Portland.**

N Rate (kg N·ha^{-1})	TSWV	INSV	TSV	DMV-Holland	DMV-D10	DMV-Portland
				% Incidence in 2020		
0	7.1	0.0	9.5	4.8	14.3	2.4
56	0.0	2.4	4.8	4.8	9.5	2.4
112	7.1	0.0	9.5	2.4	9.5	0.0
168	0.0	0.0	7.1	4.8	26.2	2.4
224	0.0	0.0	4.8	4.8	14.3	4.8
				% Incidence in 2021		
0	0.0	0.0	0.0	7.1	0.0	7.1
56	0.0	0.0	0.0	7.1	0.0	7.1
112	0.0	0.0	0.0	2.4	0.0	2.4
168	0.0	0.0	0.0	7.1	0.0	7.1
224	0.0	0.0	0.0	4.8	0.0	2.4

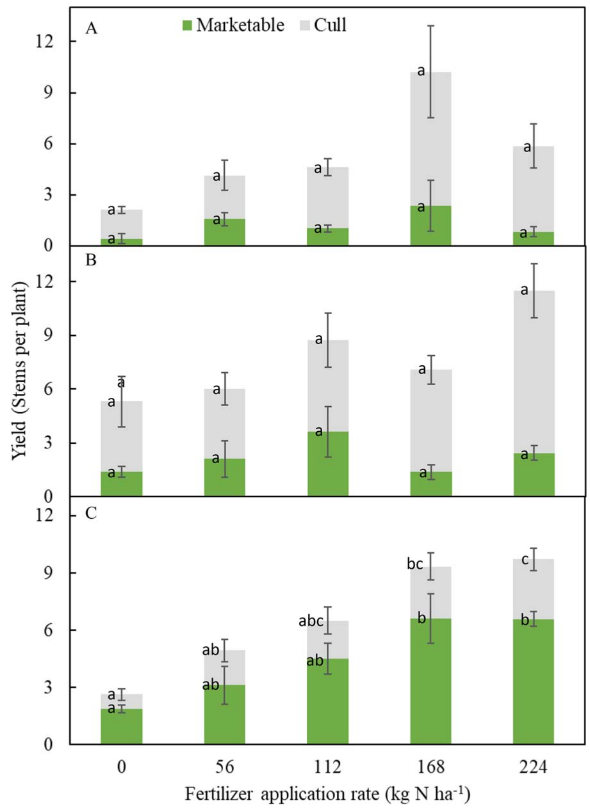

Fig. 1. Mean (±SE) yield as the total of marketable (green bars) and cull (gray bars) stems per dahlia plant by nitrogen (N) fertilizer application rate of 0, 56, 112, 168, and 224 kg ha^{-1} (0, 50, 100, 150, 200 lb N·A^{-1}) and growing year A) 2019, B) 2020, and C) 2021. Lower-case letters indicate significance among nitrogen rates each year according to Tukey HSD test at $\alpha = 0.05$.

virus symptoms are identified, culling plants to prevent further virus spread is recommended, though growers may be less inclined to do this and tend to keep virus-infected stock for some yield as opposed to none. As infected plants are grown, increases in virus incidence can be reduced or prevented by managing disease vectors, such as aphids (e.g., *Myzus persicae* S.), thrips (*Frankliniella occidentalis* P.), 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). Increasing awareness of the high potential for acquiring stock with virus(es) is important for outreach efforts with growers, as well as within the dahlia production industry.

Marketable and total yields. Nitrogen fertilizer application rates of 168 and 224 kg N·ha^{-1} (150 and 200 lb N·A^{-1}) resulted in the greatest marketable and total yields when virus incidence was managed by using virus-free cuttings in 2021. In 2019 and 2020, the rates from 112 to 224 kg N·ha^{-1} (100 to 200 lb N·A^{-1}) applications were most productive, but overall plant mortality and symptomatic response to virus infection were high and overshadowed results compared to 2021 (Fig. 1). In 2019, mean (±SE) yield increased from 0.5 (±0.2) marketable and 2.1 (±0.2) total stems per plant with no N fertilizer to 2.4 (±1.4) marketable and 10.4 (±2.7) total stems per plant with 168 kg N·ha^{-1} (150 lb N·A^{-1}) (Fig. 1A). In 2020, yield increased from 1.4 (±0.3) marketable and 5.3 total (±1.4) stems per plant with no N fertilizer to 3.6 (±1.4) marketable and 8.7 (±1.5) total stems per plant with 112 kg N·ha^{-1} (100 lb N·A^{-1}), while the mean total yield was greatest at 11.5 stems per plant with 224 kg N·ha^{-1} (200 lb N·A^{-1}) (Fig. 1B). By securing certified stock in 2021, yield improved and marketability increased from 26% to 66% of harvested stems (Fig. 1C). The 168 and 224 kg N·ha^{-1} (150 and 200 lb N·A^{-1}) treatments produced similar yields in 2021, with respective means of 6.6 (±1.3) and 6.6 (±0.4) marketable stems per plant, and 9.3 (±0.7) and 9.7 (±0.6) total stems per plant, while yield declined with decreasing N rate to 1.9 (±0.2) marketable and 2.6 (±0.3) total stems per plant in the control (Fig. 1C). Additionally in 2021, marketable and total yields were significantly greater among the 168 and 224 kg N·ha^{-1} (150 and 200 lb N·A^{-1}) rates than the control ($p<0.05$), while the total yield at 224 kg N·ha^{-1} (200 lb N·A^{-1}) was also significantly greater than that with 56 kg N·ha^{-1} (50 lb N·A^{-1}) ($p<0.05$) (Fig. 1C). Though stem production and marketability increased with greater N rates, the production of short, and hence culled, stems was still relatively high and likely limited by the daily temperature dynamics of Northern Utah's semi-arid climate. During the growing season, the average daily maximum temperatures during the day were greater than optimal for bloom (>25 C, 77 F) and the average daily minimum temperatures at night were lower than optimal (<15 C, 59 F) (Brøndum and Heins 1993).

The total yield in previous research, which primarily tested cultivars within a species with smaller bloom size, reached nine to ten stems per plant with rates up to 100 kg N·ha^{-1} (89 lb N·A^{-1}) (Prasad et al. 2018, Barik 2017, Gani et al. 2007). Four to six stems per plant of 'Café au Lait' were reached with N applications below 100 kg N·ha^{-1} (89 lb N·A^{-1}), while nine to ten stems were reached at greater rates, indicating greater nutrient demand by dinnerplate cultivars in cut flower production, even in Northern Utah, a region with shorter frost-free growing seasons. This highlights the importance of testing fertilizer applications greater than 100 kg N·ha^{-1} (89 lb N·A^{-1}) for large dahlia types to determine maximum yield goals and establish economic optimums for small farms, where land is a premium and limited resource.

Other metrics of plant response to N included tuber production, N-content of leaf tissue, stem length, and bloom diameter, all of which tended to increase with greater N, but only tuber production had statistical significance. The mean number of tubers produced per plant increased from 4 (±3) to 6 (±5) in 2020, and 3 (±0.7) to 4 (±0.7) in 2021, with plants in the 0-rate control producing the minimum number of tubers and the maximum occurring with the 224 kg N·ha^{-1} (200 lb N·A^{-1}) application rate. The mean tuber weight per plant ranged from 200 (±200) to 300 g (±200) in 2020, and 200 (±100) to 400 g (±100) in 2021, with plants receiving no N (0-rate control) producing the minimum mean weight and plants treated with 224 kg N·ha^{-1} producing the maximum. There were no differences in the number of tubers per plant or tuber weight in

2020 ($p>0.05$), while in 2021, plants treated with 224 kg N·ha^{-1} (200 lb N·A^{-1}) produced significantly more tubers and at greater weights than plants in the 0-rate control ($p<0.05$). The N content of leaf tissue before the onset of first bloom ranged from 2.9 to 3.5% in 2021, with the minimum and maximum concentrations from the control and 224 kg N·ha^{-1} (200 lb N·A^{-1}) application rates, respectively. The mean marketable stem length (±SE) ranged from 200 (±8) to 214 (±10) mm across application rates in 2019, 178 (±6) to 233 (±30) mm in 2020, and 175 (±7) to 192 (±7) mm in 2021. Bloom diameter ranged from 152 (±5) to 170 (±6) mm in 2019, 145 (±3) to 178 (±21) mm in 2020, and 157 (±2) to 167 (±10) mm in 2021, with the greatest diameters associated with the greatest N rates.

Economics. Based on partial enterprise budgets of 2021 marketable yields, positive economic returns of \$18.73 and \$18.30 per m^2 were produced with the 168 and 224 kg N·ha^{-1} (150 and 200 lb N·A^{-1}) application rates, while marketable yields from 0, 56, and 112 kg N·ha^{-1} (0, 50, and 100 lb N·A^{-1}) rates produced negative returns of \$78.43, \$37.00, and \$20.00 per m^2, respectively. As the 168 and 224 kg N·ha^{-1} (150 and 200 lb N·A^{-1}) rates produced similar yields, hence receipts, returns were maximized with the lower rate by reducing the fertilizer input cost, making 168 kg N·ha^{-1} (150 lb N·A^{-1}) the economic optimum. Moreover, this reinforces (and refines for the U.S. Intermountain West) the American Dahlia Society (2001) recommendation to not exceed 195 kg N·ha^{-1} (174 lb N·A^{-1}), as there was not a significant yield increase from 168 to 224 kg N·ha^{-1} (150 and 200 lb N·A^{-1}) and only a decrease in the economic optimum after 168 kg N·ha^{-1} (150 lb N·A^{-1}). With a potential for net returns at \$18.73 m^{-2}, dahlias represent a premium high-value crop for small farms. In Utah, cut flowers are redefining the profit potential on limited land, as more traditional high-value crops, such as red peppers (*Capsicum annum* L.), produced returns of \$3.03 m^{-2} (Drost and Ward 2019). Returns from dahlia are similar to other Utah-produced cut flowers, such as snapdragons at \$25.70 per m^2 and peonies at \$26.18 (Lewis et al. 2021b, Lewis et al. 2023). The timing of dahlia production also provides growers with later season returns, thus complementing early-season cut flowers, such as anemone (*Anemone coronaria* L.) and ranunculus (*Ranunculus asiaticus* L.) that complete blooming by May to June, as a second crop (Rauter et al. 2022a, Rauter et al. 2022b). As many farms rely on saving, dividing, and replanting dahlia tubers each year, greater N rates may also help increase production in subsequent years for small farms, as greater N use increased tuber production in 2021.

Harvest timing. The harvest timing thresholds (T20, T50, T80) generally occurred earlier with increased N, apart from the first year when virus infection overwhelmed plant response to fertilizer rates. In 2019, harvest began 74 days after transplant (August 12) for all application rates and plants in the 0-rate control then reached T20, T50, and T80 at 83, 98, and 107 days after transplant, respectively (Fig. 2A). Plants with any N fertilizer reached T20 at 90 to 94 days, T50 at 99 to 104 days, and T80 at 106 to 112 days

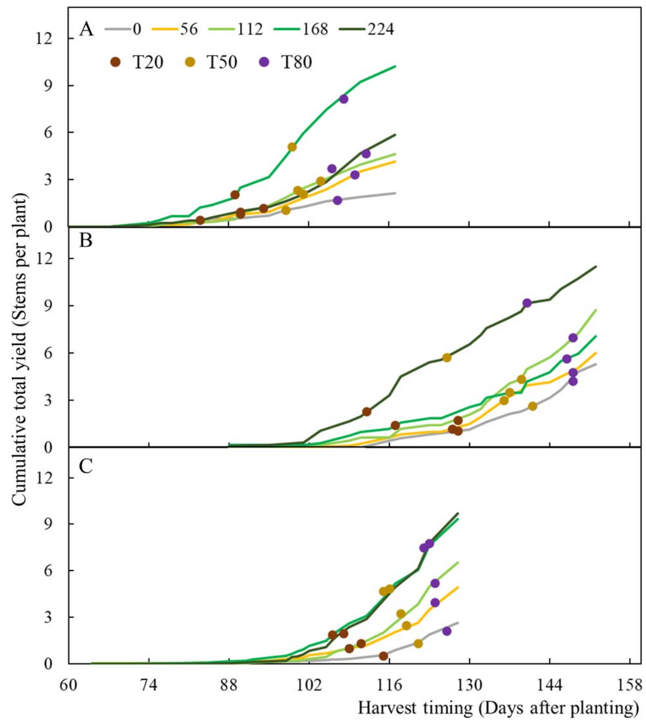

Fig. 2. Cumulative yield (marketable plus culled stems) in stems per dahlia plant for 0, 56, 112, 168, and 224 kg N·ha^{-1} (0, 50, 100, 150, 200 lb N·A^{-1}) rates across each growing season in A) 2019, B) 2020, and C) 2021. T20 (red circles), T50 (yellow circles), and T80 (purple circles) indicate the mean timing of 20%, 50% and 80% of the final cumulative total per application rate. Plants that succumbed to virus infection were excluded from this figure.

and no differences in timing were significant 2019 ($p>0.05$). In 2020, harvest began at 88 days after planting (August 11) with 168 and 224 kg N·ha^{-1} (150 and 200 lb N·A^{-1}) application rates, at 101 days (August 24) with 56 and 112 kg N·ha^{-1} (50 and 100 lb N·A^{-1}), and at 116 days (September 8) for plants in the control (Fig. 2B). The peak harvest period of T20 to T80 occurred up to 14 days earlier for plants fertilized with 168 or 224 kg N·ha^{-1} (150 or 200 lb N·A^{-1}) compared to those with lower N-fertilizer rates (Fig. 2B). Plants with 224 kg N·ha^{-1} (200 lb N·A^{-1}) reached T50 significantly earlier than those in the control ($p=0.0301$). In 2021, harvest began 64 to 86 days after transplant (July 27 to August 18), and the three harvest thresholds occurred earlier with increased N (Fig. 2C). Plants with 168 kg N·ha^{-1} (150 lb N·A^{-1}) reached T20, T50, and T80 first, at 106, 115, and 122 days, respectively, followed by plants with 224 kg N·ha^{-1} (200 lb N·A^{-1}) that reached these thresholds one to two days later (Fig. 2C). Plants with lower N-rates took an additional two to nine days to reach these thresholds, with plants in the control delayed the most, though no differences in timing were significant in 2021 ($p>0.05$).

The peak harvest thresholds of T20, T50, and T80 occurred at the same time or up to 14 days earlier for plants fertilized with 168 or 224 kg N·ha^{-1} (150 or 200 lb N·A^{-1}) compared to those with lower N fertilizer rates in 2020 and 2021. In 2021, T80 occurred within three days across all N rates, indicating that the greater N rates not only advanced, but also sustained production, thus resulting in the longest production period. The production season across N-rates

Table 3. **Mean (±SE) soil test nitrate-nitrogen (N), Olsen phosphorus (P), and Olsen potassium (K) in mg·kg^{-1}; salinity (EC) in dS·m^{-1}; and pH from spring and fall sampling during 2019 to 2021. Mean (minimum to maximum) total yield in stems per plant are also listed each year. Data represent all N treatments at the Utah Agricultural Experiment Station (UAES) - Greenville Research Farm trial in North Logan, Utah, and six grower participants across Utah's Wasatch Front.**

		2019		2020		2021	
Soil Test	**Unit**	**Spring**	**Fall**	**Spring**	**Fall**	**Spring**	**Fall**
		UAES - Greenville Research Farm					
N		1.9 (0.1)	1.5 (0.1)	2.2 (0.1)	4.5 (0.6)	1.9 (0.1)	0.8 (0.0)
P	mg·g^{-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)
K		97.8 (2.9)	91.0 (1.4)	81.5 (2.1)	129 (2.5)	117 (2.7)	111 (4.0)
EC	dS·m^{-1}	0.3 (0.0)	0.4 (0.0)	0.3 (0.0)	0.6 (0.0)	0.5 (0.0)	0.5 (0.0)
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 to 10)		8 (5 to 11)		8 (3 to 10)	
		Grower participant farms (n=6)					
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)
P	mg·g^{-1}	114 (30.8)	128 (32.0)	130 (29.5)	40.5 (7.2)	126 (21.5)	141 (37.0)
K		517 (101)	545 (161)	542 (44.3)	591 (83.7)	592 (90.7)	649 (22.4)
EC	dS·m^{-1}	1.2 (0.4)	1.3 (0.2)	1.6 (0.2)	2.0 (0.0)	3.2 (1.1)	1.8 (0.2)
pH	—	7.7 (0.01)	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 to 4)		2 (0 to 5)		0.5 (0 to 2)	

ended on the date of first frost, however, which was within two weeks of T80 each year. Previous research highlighted that added nitrogen did not delay the onset of flowering by more than one week when rates were up to 100 kg N·ha^{-1} (89 lb N·A^{-1}) (Barik 2017, Prasad et al. 2018), while first bud was delayed by only four days when rates increased from 100 to 300 kg N·ha^{-1} (89 to 267 lb N·A^{-1}) (Gupta et al. 2016). However, the timing of peak bloom, and hence production, was unreported. For dinnerplate cultivars, nutrient demand is greater and increased N rates improved yield without a delay in production, and often advancing it. Application of N-rates that are optimal for plant development and not excessive, have been shown to advance growth and maturity compared to plants that are deficient from low rates (e.g., Singh et al. 1999). Evaluating the timing of key harvest thresholds in response to fertilizer rates helps transfer research findings into local recommendations for cut flower farms.

Soil test values and grower-participant study. The primary macronutrient levels in the soil did not exceed optimal rates at the UAES Greenville Research Farm, but the mean concentrations with on-farm participants were high to excessively high at all sampling dates, particularly soil test P (Table 3). Soil-test N remained low across all study years at the research farm, and variability was minimal among spring versus fall soil-test values (i.e., samples collected before any fertilizer application in the spring and within one month after final harvest). This indicated efficient N use through plant uptake, as N was applied as a split application, irrigation was closely monitored, and rainfall was minimal, thus leaching or denitrification potential were low. Similarly, in other soil fertility studies with split applications of N on crops with tuberous root structures, such as potato (*Solanum tuberosum* L.), initial soil-nitrogen increased after fertilizer application, particularly after the first input, and were near that of an unfertilized soil by the time of harvest (Rens et al. 2016). Soil test P and K also did not exceed optimum levels at the research station by applying fertilizer based on spring soil test results, with equivalent rates up to 337 kg P_2O_5 or K_2O ha^{-1} (300 lb·A^{-1}) recommended for Western soils rated very low (<10 ppm soil test P and <70 ppm soil test K), up to 225 kg P_2O_5 or K_2O ha^{-1} (200 lb·A^{-1}) for soils rated low (10 to 19 ppm soil test P and 71 to 125 ppm soil test K), and 34 kg P_2O_5 ha^{-1} (30 lb P_2O_5 A^{-1}) and 0 K_2O ha^{-1} (0 lb K_2O A^{-1}) for soils rated optimal (20 to 30 ppm soil test P and 125 to 400 soil test K) (Cardon et al. 2008, Horneck et al. 2011).

Similarly, mean soil salinity levels remained less than 1 dS·m^{-1} throughout the duration of the study at the UAES Greenville Research Farm, while the mean values for grower participants were elevated and increased from 1.2 (±0.4) in 2019 to 3.2 (±1.1) by 2021. A soil salinity of 2 dS·m^{-1} is considered the threshold for yield decline for many horticultural crops (García-Capparós and Lao 2018), while the maximum salinity value of on-farm participants by 2021 was above 4 dS·m^{-1}, the threshold for soils to be classified as saline (FAO 1988). Though the soil salinity thresholds for dahlia have not been quantified, their salinity tolerance for irrigation water is low, at 1.1 dS·m^{-1} (AWQC 2019). At the same time, the grower participant yields were the lowest in 2021 (Table 3), despite using certified stock, which further indicated that increasing soil salinity from nutrient management practices likely inhibited plant growth and bloom production.

The soil test results from the grower participants demonstrated the need for continued public outreach and extension for fertility management, and the consequences of both reliance on and overapplication of compost-based amendments, particularly when applied based on intuition over soil test reports. Most growers indicated annual use of composts or manures, which are associated with elevated soil test P and K, as well as elevated salinity in semi-arid and arid climates, which lack rainfall to leach away excess salts (Gondek et al. 2020, Hao and Chang 2003, Stock et al. 2020). Excessive application of nutrients can also lead to greater input costs and heightened risk pollution from nutrient runoff (Pant et al. 2012). As soils accumulated P and K, and growers continued use of compost, an amendment that contains all primary macronutrients (Stock et al. 2019), the soil became enriched and reached high to excessively high fertility values.

In conclusion, proper nutrient management is vital for optimal yield production in dahlias. This study indicated that nitrogen rates of 168 and 224 kg N·ha^{-1} (150 and 200 lb N·A^{-1}) produced greater yields, while application of 168 kg N·ha^{-1} (150 lb N·A^{-1}) was economically efficient by reducing input costs without a change in yield. Regular soil testing and following nutrient application rate recommendations are critical for sustainable soil fertility management. Using soil amendments, such as compost to reach soil test phosphorus and potassium requirements and supplementing additional nitrogen needs with N-only fertilizers helps maintain optimal macronutrient levels without excessive buildup of nutrients or salts. Virus screening is also necessary for dahlia production, as virus infection severely stunts production and is widespread. With careful management of soil and plant health, dahlias are a premium, high-value crop for small farms.

Literature Cited

Ahmad, I., J.M. Dole, and P. Nelson. 2012. Nitrogen application rate, leaf position and age affect leaf nutrient status of five specialty cut flowers. Sci. Hortic. 142:14–22. DOI: 10.1016/j.scienta.2012.04.009.

American Dahlia Society (ADS). 2001. Nutrients for dahlias. https://dahlia.org/docsinfo/articles/nutrients-for-dahlias/. Accessed 08 September 2023.

Australian Water Quality Centre (AWQC). 2019. Groundwater salinity. Department of Water, Land and Biodiversity Conservation. Groundwater Group Fact Sheet. https://underdaledrillers.com.au/wp-content/uploads/2019/09/groundwater-salinity-chart.pdf. Accessed 10 August 2022.

Barik, I. 2017. Effect of N, P, K and organic manures on flower yield and flower quality of dahlia (*Dahlia variabilis*) hybrid 'Eternity Sports'. Environ. Ecol. 35(4E):3664–3668.

Brøndum, J.J., and R.D. Heins. 1993. Modeling temperature and photoperiod effects on growth and development of Dahlia. J. Amer. Soc. Hort. Sci. 118(1):36–42. DOI: 10.21273/JASHS.118.1.36.

Brunt, A.A. 1971. Some hosts and properties of dahlia mosaic virus. Ann. Appl. Biol. 67(3): 357–368. DOI: 10.1111/j.1744-7348.1971.tb02937.x.

Cardon, G.E., J. Kotuby-Amacher, P. Hole, and R. Koenig. 2008. Understanding your soil test report. Utah State University Extension. Paper 825. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1825&context=extension_curall. Accessed 29 June 2022.

Curtis, C. and M.N. Stock. 2023. Research report: Growing a new cut flower industry: markets needs and preferences. J. Food Dist. Res. 54(1):1–7. https://www.fdrsinc.org/wp-content/uploads/2023/04/JFDR54.1_1_Curtis.pdf. Accessed 08 September 2023.

Drost, D. and R. Ward. 2019. Enterprise budgets: Red peppers with shade. 2019 Utah Agricultural Statistics and Annual Summary Report. p. 70–72. https://ag.utah.gov/wp-content/uploads/2019/09/2019-Utah-Agricultural-Statistics-and-Annual-Summary.pdf. Accessed 29 June 2022.

Food and Agriculture Organization of the United Nations (FAO). 1988. Salt-affected soils and their management. Bulletin 39. FAO, Rome. https://www.fao.org/3/x5871e/x5871e00.htm#Contents. Accessed 10 August 2022.

Flynn, R., R.D. Baker, and S.T. Ball. 1999. Sampling for plant tissue analysis. New Mexico State University, College of Agricultural, Consumer, and Environmental Sciences. Guide A-123. https://pubs.nmsu.edu/_a/A123/. Accessed 29 June 2022.

Fry, W.E. 2012. Principles of plant disease management. Academic Press. 378 pp.

Gani, G., M.A. Beigh, R.A. Lone, A.B. Nanda, and K. Hussein. 2007. Effect of different levels of nitrogen and phosphorus on growth and flowering of dahlia cv. 'Kenya yellow'. J. Plant Sci. Res. 23(1):59–62.

García-Caparrós, P. and M.T. Lao. 2018. The effects of salt stress on ornamental plants and integrative cultivation practices. Sci. Hortic-Amsterdam. 240:430–439. DOI: 10.1016/j.scienta.2018.06.022.

Gondek, M., D.C. Weindorf, C. Thiel, and G. Kleinheinz. 2020. Soluble salts in compost and their effects on soil and plants: A review. Compost Sci. Util. 28(2):59–75. DOI: 10.1080/1065657x.2020.1772906.

Gupta, Y.C., R.V. Dinesh, B. Kashyap, S. Bhatia, and P. Sharma. 2016. Effect of N and K on growth, flowering, and multiplication of dahlia (*Dahlia variabilis*) cv. 'Giani Zail Singh'. Curr. Hortic. 4(2):48–53.

Hao, X. and C. Chang. 2003. Does long-term heavy cattle manure application increase salinity of a clay loam soil in semi-arid southern Alberta? Agric. Eco. Environ. 94(1):89–103. DOI: 10.1016/s0167-8809(02)00008-7.

Horneck, D.A., D.M. Sullivan, J.S. Owen, and J.M. Hart. 2011. Soil test interpretation guide. Oregon State University Extension Service. EC 1478. https://www.canr.msu.edu/foodsystems/uploads/files/soil_test_interpretation.pdf. Accessed 10 August 2022.

Hosack, P. and L. Miller. 2017. Preventing and managing plant diseases. University of Missouri Extension. Missouri Master Gardener Core Manual. Chapter 13.

Knepel, K. 2003. Determination of nitrate in 2M KCl soil extracts by flow injection analysis. QuikChem Method 12-107-04-1-B. Lachat Instruments, Loveland, CO. 18 pp.

Kumar, N., V.M. Prasad, and N.P. Yadav. 2019. Effect of chemical fertilizers and bio fertilizers on flower yield, tuberous root yield and quality parameter on dahlia (*Dahlia variabilis L.*) cv. 'Kenya orange'. J. Pharmacogn. Phytochem. 8(4):2265–2267.

Lewis, M., M.N. Stock, B. Black, D. Drost, and X. Dai. 2023. High tunnel and field production of early-season peonies. HortScience 58(4):389–394. DOI: 10.21273/HORTSCI16942-22.

Lewis, M., M. Stock, R. Ward, B. Black, and D. Drost. 2021a. Peony cut flower production budget, one field, Northern Utah, 2020. Utah State University Extension. Paper 2166. https://digitalcommons.usu.edu/extension_curall/2166. Accessed 29 June 2022.

Lewis, M., M. Stock, B. Black, D. Drost, and X. Dai. 2021b. Improving snapdragon cut flower production through high tunnel season extension, transplant timing, and cultivar selection. HortScience 56(10):1206–1212.

Lewis, M., M. Stock, R. Ward, B. Black, and D. Drost. 2020. Snapdragon cut flower production budget, one high tunnel, Northern Utah, 2020. Utah State University Extension. Paper 2140. https://digitalcommons.usu.edu/extension_curall/2140. Accessed 29 June 2022.

Ma, B.L., M. Lianne, E. Dwyer, and G. Gregorich. 1999. Soil nitrogen amendment effects on seasonal nitrogen mineralization and nitrogen cycling in maize production. Agron. J. 91:1003–1009. DOI: 10.2134/agronj1999.9161003x.

Moorman, G.W. 2011. Impatiens necrotic spot virus. Penn State Extension. https://extension.psu.edu/impatiens-necrotic-spot-virus. Accessed 29 June 2022.

Naziki, I.T., R.A. Lone, and G. Gani. 2017. Response of cut dahlia cv. 'Pink Attraction' to inorganic nutrition. Agric. Update. 12:1396–1399. DOI: 10.15740/HAS/AU/12.TECHSEAR(5)2017/1396-1399.

Olsen, S.R. and L.E. Sommers. 1982. Phosphorus. p. 403–430 *In* A. L. Page, et al. (Eds.), Methods of soil analysis: Part 2. Chemical and microbiological properties. 2nd edition. Madison, WI: American Society of Agronomy.

Oliver, F. 2022. Urban soil chemical and nutrient management issues facing emerging small grower enterprises in Utah. Utah State University. Master's Thesis. Publication No. 8513. https://digitalcommons.usu.edu/etd/8513/. Accessed 29 June 2022.

Pahalawatta, V., R. Miglino, K.B. Druffel, A. Jodlowska, A.R. van Schadewijk, and H.R. Pappu. 2007. Incidence and relative prevalence of distinct caulimoviruses (genus Caulimovirus, family Caulimoviridae) associated with dahlia mosaic in *Dahlia variabilis*. Plant Dis. 91(9):1194–1197. DOI: 10.1094/PDIS-91-9-1194.

Pant, A.P., T.J.K Radovich, N.V. Hue, and R.E. Paull. 2012. Biochemical properties of compost tea associated with compost quality and effects on pak choi growth. Scientia Horticulturae 148:138–146. DOI: 10.1016/j.scienta.2012.09.019.

Prasad, S.H., V. Prasad, S.K. Goutham, and S.C Bose. 2018. Effect of integrated nutrient management on flowering and flower yield of dahlia (*Dahlia variabilis* L.) CV. Kenya Orange. Plant Arch. 18(1):795–798.

Rauter, S., M. Stock, B. Black, D. Drost, and X. Dai. 2022a. Overwintering improves ranunculus cut flower production in the US Intermountain West. Horticulturae 8(12):1128. DOI: 10.3390/horticulturae8121128.

Rauter, S., M. Stock, B. Black, D. Drost, and X. Dai. 2022b. Anemone cut flower timing, yield, and quality in a high-elevation field and high tunnel. Horticulturae. 9(2):3390. DOI: 10.3390/horticulturae9010002.

Rens, L., L. Zotarelli, A. Alva, D. Rowland, G. Liu, and K. Morgan. 2016. Fertilizer nitrogen uptake efficiencies for potato as influenced by application timing. Nutr. Cycl. Agroecosystems. 104(2): 175–185. DOI: 10.1007/s10705-016-9765-2.

Rhoades, J.D. 1982. Soluble Salts. p. 167–179 *In* A. L. Page et al. (Eds.), Methods of Soil Analysis: Part 2: Chemical and Microbiological Properties. 2nd edition. Madison, WI: American Society of Agronomy.

Sheergojri, G.A., Z.A. Rather, F.U. Khan, I.T. Nazki, and Z.A. Qadri. 2013. Effect of chemical fertilizers and bio-inoculants on growth and flowering of dahlia (*Dahlia variabilies* Desf.) cv. ‘Pink Attraction’. Appl. Biol. Res. 15(2):121–129.

Sheldrick, B.H. and C. Wang. 1993. Particle-size distribution. p. 499–511 *In* Carter, M. R. (Ed.), Soil Sampling and Methods of Analysis, Ann Arbor, MI: Canadian Society of Soil Science, Lewis Publishers.

Shimizu-Yumoto, H. and K. Ichimura. 2013. Postharvest characteristics of cut dahlia flowers with a focus on ethylene and effectiveness of 6-benzylaminopurine treatments in extending vase life. Postharvest Biol. Tech. 86:479–486.

Siegner, A., J. Sowerwine, and C. Acey. 2018. Does urban agriculture improve food security? Examining the nexus of food access and distribution of urban produced foods in the United States: A systematic review. Sustainability 10(9):2988. DOI: 10.3390/su10092988.

Singh U., P. Wilkens, V. Chude, and S. Oikeh. 1999. Predicting the effect of nitrogen deficiency on crop growth duration and yield. Proceedings of the Fourth International Conference on Precision Agriculture. Part A and Part B: 1379–1393. St. Paul, MN, 19–22 July 1998. DOI: 10.2134/1999.precisionagproc4.c40b.

Spectrum Analytic Inc. 2009. Illustrated guide to sampling for plant analysis. https://www.spectrumanalytic.com/services/analysis/plantguide.pdf. Accessed 29 June 2022.

Stock, M. 2020. Survey of cut flower growers. [Unpublished raw data, collected on 05 March 2020]. Utah Urban and Small Farms Conference: Cut Flowers Session. Utah State University. West Valley City, UT.

Stock, M., A. Pratt, C. Nischwitz, E. Oliver, K. Wagner, and N. Volesky. 2023. Dahlia cut flower production in Utah. Utah State University Extension. Paper 2320. https://digitalcommons.usu.edu/extension_curall/2320/. Accessed 28 April 2023.

Stock, M., T. Maughan, and P.R. Grossl. 2020. Urban garden soils: Testing and management. Utah State University Extension. Paper 2116. https://digitalcommons.usu.edu/extension_curall/2116. Accessed 29 June 2022.

Stock, M., T. Maughan, and R. Miller. 2019. Sustainable manure and compost application: Garden and micro farm guidelines. Utah State University Extension. Paper 2047. https://digitalcommons.usu.edu/extension_curall/2047. Accessed 10 August 2022.

USDA-Agricultural Research Service (ARS). 2012. USDA plant hardiness zone map. Plant Hardiness. https://planthardiness.ars.usda.gov/. Accessed 19 April 2022.

Utah Climate Center. 2022. Utah freeze dates. Utah State University. https://climate.usu.edu/reports/newFreezeDates.php. Accessed 30 June 2022.

USDA-National Agriculture Statistics Service (NASS). 2022. NASS highlights: 2021 floriculture crops. Washington D.C. https://www.nass.usda.gov/Publications/Highlights/2022/Floriculture_Highlights_07.pdf. Accessed 01 July 2022.

USDA-National Agriculture Statistics Service (NASS). 2021. Floriculture crops 2020 summary. Washington D.C. https://downloads.usda.library.cornell.edu/usda-esmis/files/0p0966899/s4656b62g/g445d913v/floran21.pdf. Accessed 01 July 2022.

Wada, K.C. and K. Takeno. 2010. Stress-induced flowering. Plant Signal. Behav. 5(8): 944–947. DOI: 10.4161/psb.5.8.11826.

Western Regional Climate Center (WRCC). 2022. NCDC 1981-2010 Monthly normals: Utah State University, Logan, Utah. https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?utloga. Accessed 18 July 2022.