Climate Ready Landscape Plants: Aesthetic Qualities and Physiology of Landscape Plants in Response to Deficit Irrigation Across the Western U.S.

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Abstract

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Climate change is causing more frequent and severe droughts in the Western U.S., while concurrently, about 70% of urban water use is delegated to landscape irrigation. Therefore, water conservation techniques in the horticultural space, such as planting water use efficient landscape plants, will be essential to decrease irrigation consumption. Five different taxa, *Hibiscus syriacus* ‘Gandini Santiago’ Purple Pillar®, *Hibiscus syriacus* 'ORSTHIB5x1' PPAF, *Rosa* ‘Meibenbino’ Petite Knock Out®, *Rosa* ‘ChewPatout’ Oso Easy® Urban Legend®, and *Vitex* ‘SMVACBD’ Blue Diddley®, were subjected to one of three water deficit treatments in Arizona, California, Oregon, Utah, and Washington. Plants were rated on foliage quality, flowering, pest tolerance, disease resistance, vigor, and overall appearance. Growth measurements were also taken to calculate a plant growth index and relative plant growth index. Stomatal conductance and the efficiency of Photosystem II (Φ_{PSII}) were measured when the treatments were in full effect and were compared to the aesthetic ratings to get a broad picture of plant health. Overall, at individual institutions treatment did not have a significant effect on aesthetic qualities but did have an effect on growth. However, between institutions aesthetic qualities and growth differed significantly. Stomatal conductance and Φ_{PSII} were not affected by treatment, even when controlling for light level. High stomatal conductance and Φ_{PSII} did not necessarily lead to higher aesthetic scores or greater growth. Given this, the taxa tested performed well aesthetically when watered at a lower frequency even across a large climate gradient. Since the plants were still able to retain their aesthetic value and leaf-level physiological functions when watered less frequently, utilizing the taxa tested can help landscape professionals and consumers reduce their irrigation usage. Aesthetically pleasing plants will always be in demand, therefore assessing water use of common landscape taxa will help to inform growers about plant water need.

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Introduction

In the Western United States, droughts are anticipated to increase in frequency and severity due to climate change (Ali et al., 2022). As a result, surface water supply is decreasing while groundwater extraction is increasing to keep up with human demand (Flint et al., 2018). Therefore, finding ways to conserve water such as planting water-efficient plants are critical for sustaining agricultural as well as urban ecosystems. Attempts to decrease water consumption in urban landscapes include reduced water use restrictions, targeted irrigation, using alternative water sources, or installing efficient irrigation systems (Kjelgren et al., 2000; Bijoor, 2021). Investing in water-efficient landscape plants is one long-term method for water conservation in urban landscapes considering up to 70% of urban water usage is used for residential irrigation purposes (Hayden et al., 2015; McCammon et al., 2009). Additionally, homeowners tend to irrigate more than their plants need because they are unaware of proper irrigation requirements (Knuth et al., 2018). Promoting plants with a low water requirement is a clear way to reduce overconsumption of residential water.

Overall aesthetic traits encompassing foliage quality, pest and disease resistance, vigor, and flowering are essential aspects to consider in advocating for water-wise landscape plants. The performance of landscape plants is primarily based on aesthetic values since that is an integral part of the utility of these plants (Kjelgren et al., 2000). In a survey, over 84% of homeowners wanted their yards to be visually appealing (Blaine et al., 2012), and when choosing landscape plants, aesthetic quality was the most important aspect (Hayden et al., 2015). Marketing aesthetically pleasing and low water use landscape plants will help consumers create beautiful and water-efficient gardens. In 2017, the United States horticultural industry earned

$6.1 billion from floriculture and bedding crops with an additional $5.8 billion from nursery stock crops (Census of Agriculture, 2017). Of this revenue, the Western States participating in this research accounted for approximately 24% of floriculture and bedding crop sales and 38% of nursery stock crop sales. As big producers of landscape plants, while also experiencing increased droughts, the Western U.S. is poised to promote not only attractive but also water-wise taxa.

Water-use efficient plants can reduce water waste by preventing excessive irrigation. However, selecting the plants most suitable for these conditions requires an understanding of the physiological mechanisms that promote these features. For instance, stomata, or leaf pores, respond to environmental conditions such as soil water deficit (Chaves et al., 2002; Lawson and Morison, 2004). Water leaves about 300-400 times the rate of CO_2 entering the stomata (Evans and von Caemmerer, 2017). Therefore, when stomata are open for extended periods of time, water is lost thus decreasing water use efficiency (Lambers et al., 2008). This becomes incredibly important in water deficit conditions when a plant needs to balance water loss and the assimilation of CO_2 for photosynthesis (Chaves et al., 2002; Gago et al., 2016). Consequently, stomatal conductance (g_s) is important to overall plant health and can indicate if a plant is experiencing low water conditions. Additionally, plant responses to less water can show up in the photosynthetic pathway. Part of the photosynthetic system is photosystem II (PSII) which helps to capture light in a plant (Lambers et al., 2008). Measuring the photochemical efficiency of photosystem II (ϕ_{PSII}), is a way to indicate the efficiency of photosynthesis which can highlight stress in a plant (Maxwell and Johnson, 2000). Assessing both stomatal conductance and ϕ_{PSII} will help determine how plants are responding physiologically to water deficit conditions.

While there have been studies of water use efficiency in landscape plants (Huang and Gao, 1999; Chapman and Augé, 1994), few include an assessment of aesthetic qualities (Paine et al., 1992; Zollinger et al., 2006) and are older, indicating the need for updated information in a changing climate. Harp et al. (2019) gives a rigorous overview of the aesthetic qualities of 60 rose cultivars. Additionally, many physiological responses to water deficit have been studied in landscape plants (Huang and Gao, 1999; Chapman and Augé, 1994). However, few consider the overlap between physiological responses and aesthetic qualities (Zollinger et al., 2006). Currently, assessing how leaf physiology, overall appearance, and growth change across a large-scale climate gradient for landscape plants experiencing water deficit is not common. It would be pertinent for consumers to know if specific water-efficient taxa would perform well across multiple regions.

One leading resource to estimate plant water demand in California is the Water Use Classification of Landscape Species (WUCOLS) which estimates water demand for 3,500 landscape plants (Costello and Jones, 2014). Of those plants, only 5% have irrigation recommendations based on analytical studies versus observations from horticulturalists (Costello and Jones, 2014). Additionally, this document is not updated regularly with new cultivars, leaving a gap in information for consumers. Many other Western U.S. states have yet to create a list like this. Therefore, testing and understanding how landscape plants respond to different irrigation levels across a large climate gradient will generate beneficial information for growers about low water use plants that will grow well in their region. As changes to precipitation patterns and droughts become more frequent, plants that can withstand prolonged periods of decreased water availability in the Western U.S. will be in high demand.

In this study, we aimed to evaluate aesthetic quality, growth, and leaf physiology of landscape plants across six different field sites in the Western U.S. under different water deficit scenarios. To accomplish this, five different taxa were subjected to one of three water deficit irrigation treatments. Each month, we rated the plants based on six different aesthetic quality categories: foliage quality, flowering, pest tolerance, disease resistance, vigor, and overall appearance. Additionally, growth measurements such as length, width, and height were taken each month to calculate a plant growth index (PGI) and relative plant growth index (rPGI). Stomatal conductance and ϕ_{PSII} were measured to determine physiological responses in leaves to water deficit. Our first objective we had was to see if there were specific differences in aesthetic parameters and growth between treatments for each taxon and site. We hypothesized that 1a) aesthetic ratings and growth will be higher in the high compared to low irrigation treatments across all taxa examined, and 1b) overall appearance will be rated higher in Washington, Oregon, and Utah compared to California and Arizona sites for all taxa tested because the Northern sites have lower temperatures and evapotranspiration during the growing season. Our second objective was to see if there were any significant differences in leaf physiology between treatments for each taxon and site. We hypothesized that 2a) stomatal conductance and ϕ_{PSII} will be greater in the high water treatment for all taxa, and 2b) that these parameters would vary significantly between sites. Lastly, we wanted to compare aesthetic ratings and growth with the physiological parameters measured. We hypothesized that 3) plants with higher stomatal conductance and ϕ_{PSII} will have higher aesthetic ratings and growth.

Materials and Methods

Field Setup

This study was carried out alongside the ongoing Climate Ready Landscape Plants (CRLP) project at the University of Washington (UW), the University of California Davis (UCD), the University of California Agriculture and Natural Resources South Coast Research and Extension Center (SCREC), Oregon State University North Willamette Research and Extension Center (OSU), Utah State University (USU), and the University of Arizona (UA) (Fig. 1). Between the sites, 40 total taxa were being tested, but five of those taxa found across all field sites were the focus of this study. These include *Hibiscus syriacus* ‘Gandini Santiago’ Purple Pillar®, *Hibiscus syriacus* 'ORSTHIB5x1' PPAF, *Rosa* ‘Meibenbino’ Petite Knock Out®, *Rosa* ‘ChewPatout’ Oso Easy® Urban Legend®, and *Vitex* ‘SMVACBD’ Blue Diddley®. *Rosa* ‘ChewPatout’ Oso Easy® Urban Legend® was not grown at the Arizona field site. Average high and low air temperature (℃), accumulated precipitation (cm), and accumulated reference evapotranspiration (ETo, cm) from January- December 2022 are reported for each field site in Table 1. Data was retrieved from the Washington State University AgWeatherNet (n.d.) for UW, the Bureau of Reclamation AgriMet Network (2016) for OSU, the Utah Climate Center (n.d.) for USU, the California Irrigation Management Information System (n.d.) for UCD and SCREC, and the Arizona Meteorological Network (n.d.) for UA. These were also the weather stations we used to record daily precipitation and Eto to determine irrigation timing for each site.

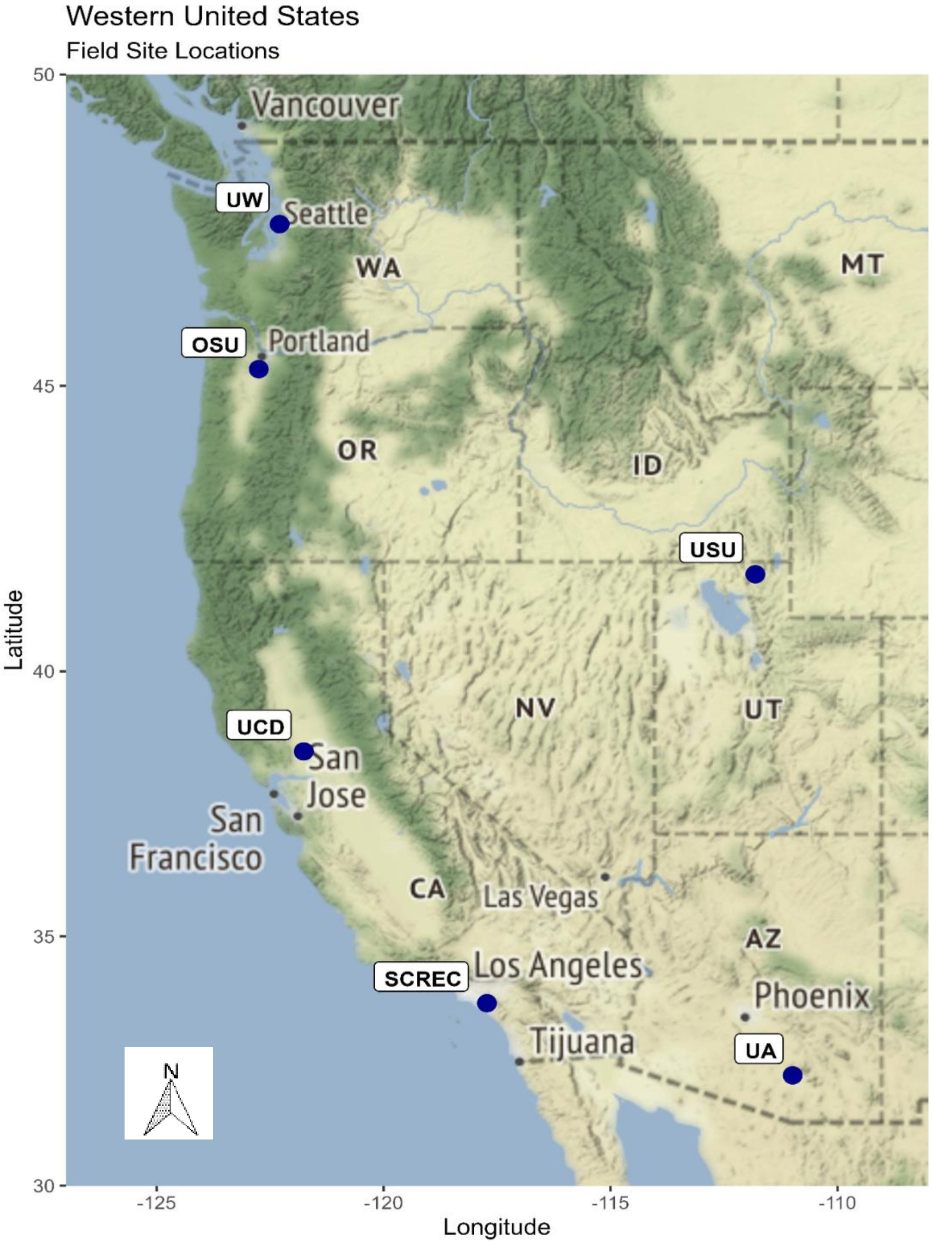

Fig. 1 A map representation of where the six study sites are in the United States. State borders are dashed grey lines. The UW site was located in Seattle, Washington, the OSU site was located in Aurora, Oregon, the USU site was located in Logan, Utah, the UCD site was located in Davis, California, the SCREC site was located in Irvine, California, and the UA site was located in Tucson, Arizona.

Table 1 Climate parameters for each study site to illustrate their differences in average high and low air temperature (°C), precipitation (cm), reference evapotranspiration (ETo, cm), soil type, and growing zone based on the USDA plant hardiness zone map (USDA-ARS, 2012). This data represents the climatic conditions averaged or accumulated from January-December 2022 during the year of this study.

Site	Average High Air Temperature (°C)	Average Low Air Temperature (°C)	Accumulated Precipitation (cm)	Accumulated ETo (cm)	Soil Type	Plant Hardiness Zone	Soil Water Holding Capacity
UW	16.2	7.3	96.0	65.9	Loamy sand	8b	7%
OSU	17.8	6.6	107.2	103.5	Willamette silt loam	8b	20%
USU	14.9	1.9	38.6	105.2	Millville silt loam	6a	18%
UCD	24.7	8.7	34.3	154.9	Yolo silty clay loam	9b	19%
SCREC	24.6	12.2	21.6	146.1	San Emigdio fine sandy loam	10a	14%
UA	29.3	11.3	21.7	168.3	Glendale silt loam	9b	20%

Plots were set up one year before treatments were implemented, giving the plants time to acclimate. The plants received irrigation at the high-water treatment during the year of establishment. The position and deficit treatment of each plant in the plot were arranged in a completely randomized design. Plants were spaced two meters away in rows one meter in width from their nearest neighbor in each direction. Each row was covered with 5-8 cm of mulch to retain moisture and reduce weeds. Within the five target taxa, there were 24 plants per taxa, with eight replicates allocated to each water deficit treatment. For this study, leaf physiological measurements were taken from four plants per treatment per taxa for *Rosa* and *Vitex* and five plants for *Hibiscus* due to the time constraints. The same number of replicates were used for the aesthetic ratings and growth measurements to match with the physiological measurements. Plants were assigned a number 1-8 per treatment, and using a random number generator were picked as representations of the five taxa.

Irrigation Setup

There were three water deficit treatments, based on reference evapotranspiration (ETo), corresponding to high, moderate, and low water need. These levels were based on the Water Use Classification of Landscape Species (WUCOLS) through the University of California Davis Center for Urban Horticulture (Costello and Jones, 2014), which were decided on by experienced horticulturalists. ETo in the WUCOLS document is defined as the water lost from a field of cool-season grass that is 10-18cm tall and not experiencing water stress (Costello and Jones, 2014). Each site had a trigger point for each irrigation treatment of centimeters of ETo accumulated until there was a loss of water equivalent to 50% of plant available water (Oki et al., 2016). The volume of water applied during an irrigation event was based on soil texture, soil water holding capacity, and an imaginary cylinder representing the root volume 1m in diameter and 0.5m deep (Reid et al., 2021). Soil water holding capacity was calculated based on the available water storage (cm per 0-100cm) for each field site’s soil type by the UC Davis Soil Resource Laboratory (n.d.) divided by one hundred. Plants were irrigated once the trigger point was reached. The treatment level determined how fast ETo accumulated, which controlled the irrigation frequency. An important distinction is that the same volume of water was applied to the plants regardless of treatment during an irrigation event. However, irrigation happened at different times based on treatment. For example, plants in the low water need treatment may only have been irrigated two times throughout the field season compared to the high treatment that was watered eight times, but when any of the treatments were irrigated plants received the same volume of water. Water was applied in pulses for uniform soil infiltration. Each site's daily ETo and precipitation were monitored by the closest weather station to the field site and documented to keep track of irrigation timing. Weather stations for each site are defined in the above *Field Setup* section. Three irrigation tubes were installed alongside each row in the plot corresponding to one of the three water deficit treatments. Each plant had an irrigation drip ring with a flow rate of 2.11 mL s^{-1} connected to the tube of its assigned treatment. All row tubing was connected to one main PVC pipe and an irrigation timer. Irrigation treatments started in April (UCD, SCREC, UA) or June (UW, USU, OSU) 2022 depending on spring weather at each site and finished at the end of September 2022.

Aesthetic Ratings and Growth Measurements

The target taxa were assessed in six categories: foliage quality, flowering, pest tolerance, disease resistance, vigor, and overall appearance. Plants were rated on a scale of one to five, with one representing a severely damaged or dying plant, two representing unacceptable appearance, three representing an average/acceptable plant, four representing a very nice plant, and five representing a top-performing, excellent plant. A score of three also indicated the lowest acceptable performance of a plant. We rated appearance once before deficit treatments started and then once every month until the treatment phase was finished. For this study, appearance ratings and growth measurements were only considered for the month of August as this was most likely the month plants at all sites would be experiencing the full effects of the water deficit treatments.

One shortcoming of the aesthetic data is that there is room for bias in scoring between sites. This problem was ameliorated by a training session with the researchers who created the rating system before treatments began. Additionally, many researchers attended the UCD open house at the beginning of the field season and were able to rate plants at that site together and compare ratings as a trial run. If multiple people were rating the plants at one field site, then taxa were split between researchers to better observe any changes over the field season. Raters also occasionally cross-checked with each other to make sure that they would rate a plant similarly.

Each plant's length (l), width (w), and height (h) in centimeters were measured at the same time as the monthly appearance ratings. These measurements were used to calculate a plant growth index (PGI, equation 1) in centimeters modified from Irmak et al. (2004).

$$\text{PGI} = \frac{h + [(l + w)/2]}{2} \tag{1}$$

Plants were measured north/south (length), east/west (width), and top of the soil to the top of the plant (height) from the furthest leaf in each direction. After baseline PGI was calculated for each plant, that measurement was used to calculate the relative plant growth index (rPGI) for each month (equation 2). The rPGI represents plant growth over the treatment period accounting for initial variation in plant size. PGI_m represents the PGI of the current month, and PGI_i represents the initial PGI value before treatments started (equation 2).

$$\text{rPGI} = \text{PGI}_m/\text{PGI}_i \tag{2}$$

Leaf Physiological Measurements

Stomatal conductance (g_s, mol m^{-2} s^{-1}), Φ_{PSII}, and ambient light conditions (Qamb, µmol m^{-2} s^{-1}) were simultaneously measured with a LI-600 Porometer/Fluorometer (LI-COR, Lincoln, Nebraska, USA) at UW, UCD, and SCREC. Measurements were taken one day before all treatments were expected to need irrigation in order to capture the most time between irrigation events for each treatment. This was done in August when plants at all sites were expected to experience the full effect of the treatments. In some cases, if one of the treatments was a day off from the other two treatments, irrigation was delayed or moved early and the new ETo was recorded. ETo was always within +/- 10% of the original irrigation treatment. Only one timepoint was recorded for g_s and Φ_{PSII} because we needed all three treatments to line up to be irrigated on the same day and this did not happen often. LI-600 configuration was set to automode with fast g_s, fluorescence, and flow rate with ambient conditions matching set to an interval of 10 minutes. All other parameters were kept at the pre-set values. Both *Hibiscus* taxa were found to be amphistomatous, meaning they have stomata on the top (adaxial) and bottom (abaxial) of the leaf. Therefore, adaxial and abaxial leaf conductance for *Hibiscus* were added together and reported as total conductance. Stomatal conductance and Φ_{PSII} were measured in the morning (8 am -11 am) in relatively consistent light conditions to reduce the influence of large weather and/or temperature fluctuations. The four newest fully expanded, non-diseased, full sun leaves per plant were measured with the LI-600. When possible, leaves were selected to represent various parts of the plant canopy. In the case of compound leaves, the pinnate leaf was measured.

Soil Moisture

Soil moisture sensors (WATERMARK, IRROMETER Company, Inc., Riverside, California, USA) were installed in August at the University of Washington field site to assess the effectiveness of each treatment. Each sensor was buried vertically so that the middle of the sensor was at a depth of 15 cm. The sensors were installed 30 cm from the center of the plant.

Thirty-nine soil moisture sensors were individually allocated to the high or low treatments. Two to three sensors were installed per treatment per taxa of the target taxa. Sensors were also installed in three open positions in the field, one in each of the three treatments. Measurements were taken on nine separate days from September 6th - 22nd, 2022. Sensor readings of 199 centibars represent an error reading and were removed.

Statistical Analysis

For all aesthetic, growth, and leaf physiological data four plants per treatment per taxa for *Rosa* and *Vitex* and five plants for *Hibiscus* were used for analysis. Results for growth were compared between treatments for each field site using a two-way analysis of variance (ANOVA) with a Tukey-Kramer test for UA and USU since their replicates per treatment were balanced. Differences in growth between treatments within a taxon were compared using a one-way ANOVA for UA and USU. A Type III Sum of Squares test was used to compare aesthetic ratings and growth between treatment for each site and each taxon for UW, OSU, UCD, and SCREC because their replicates were unbalanced. The lme function in the nlme package in R was used, and the car package was used for the Type III ANOVA. An analysis of covariance (ANCOVA) test was used to remove the effect of light level on g_s and Φ_{PSII} to discern if there was a treatment effect. A Tukey-Kramer post-hoc test was used to determine which treatments varied in g_s or Φ_{PSII}. Data were transformed based on the transformation specified by the boxcox function if assumptions were violated for an ANOVA or ANCOVA test. If the data still did not meet the assumptions for an ANOVA after a transformation, the Kruskal-Wallis test with a Dunn post-hoc test was used. As the aesthetic ratings were non-parametric data, the Kruskal-Wallis test and Dunn test were used to compare ratings between treatments for each field site and within a taxon. Pearson’s correlation matrix was calculated between all traits measured to determine their relationships. A one-tailed t-test was used to compare overall appearance scores of each taxon and site combination if they were above a ratings threshold (i.e., > 3). Soil moisture differences between high and low water treatments were analyzed using a one-tailed t-test. The significance level was based on $\alpha = 0.05$. All data were analyzed using R version 2023.3.386 for desktop computer (Posit team, 2023). (RStudio, Boston, Massachusetts, USA). ggstatsplot (Patil, 2021) was used for violin plot data visualization. Violin plots were reported with the p-value and the number of observations (n_{obs}). Descriptive statistics were reported by mean +/- standard error.

Results

Objective 1: Aesthetic Qualities and Growth

There were almost no significant treatment effects on all aesthetic ratings and growth measurements at individual field sites. The Utah State University field site stood out, showing a significant difference in height between high and low treatments (Tukey HSD $p = 0.017$) with the high treatment having a larger height on average. Additionally, overall appearance was significantly higher in the moderate versus low treatment (Fig. 2, Tukey HSD $p = 0.018$). At the Arizona field site, width was significantly larger in the moderate versus low treatment (Tukey HSD $p = 0.022$). All other traits did not vary significantly with treatment at each site. *Hibiscus syriacus* 'ORSTHIB5x1' at the Utah site did not survive with enough replicates from the time of planting.

Comparing individual taxa with treatment at each site, there were not many significant differences in aesthetic ratings (Fig. 3). While there were few treatment differences found, *Vitex* ‘SMVACBD’ and *Rosa* ‘ChewPatout’ made up the taxa with the most significant differences in parameters based on treatment (Fig. 3). Within those differences, the moderate and high treatments scored higher than the lower of the treatments (i.e. in a high - moderate comparison the high treatment scored higher). There were some differences in rPGI between treatments for SCREC (0.0489) and UW ($p = 0.037$) for *Vitex* ‘SMVACBD’, and PGI for UA (low-moderate, Tukey HSD $p = 0.043$) for *Hibiscus syriacus* ‘Gandini Santiago’. Of the two treatments that differed, the higher treatment tended to have larger growth. Most taxa scored at least an average overall appearance rating of three, which is considered the lowest acceptable appearance standard in our scoring system (Fig. 4). *Hibiscus* ‘Gandini Santiago’ (SCREC), and *Rosa* ‘ChewPatout’ (UW, UCD) scored equal to or above a four, which is considered a very good aesthetic score.

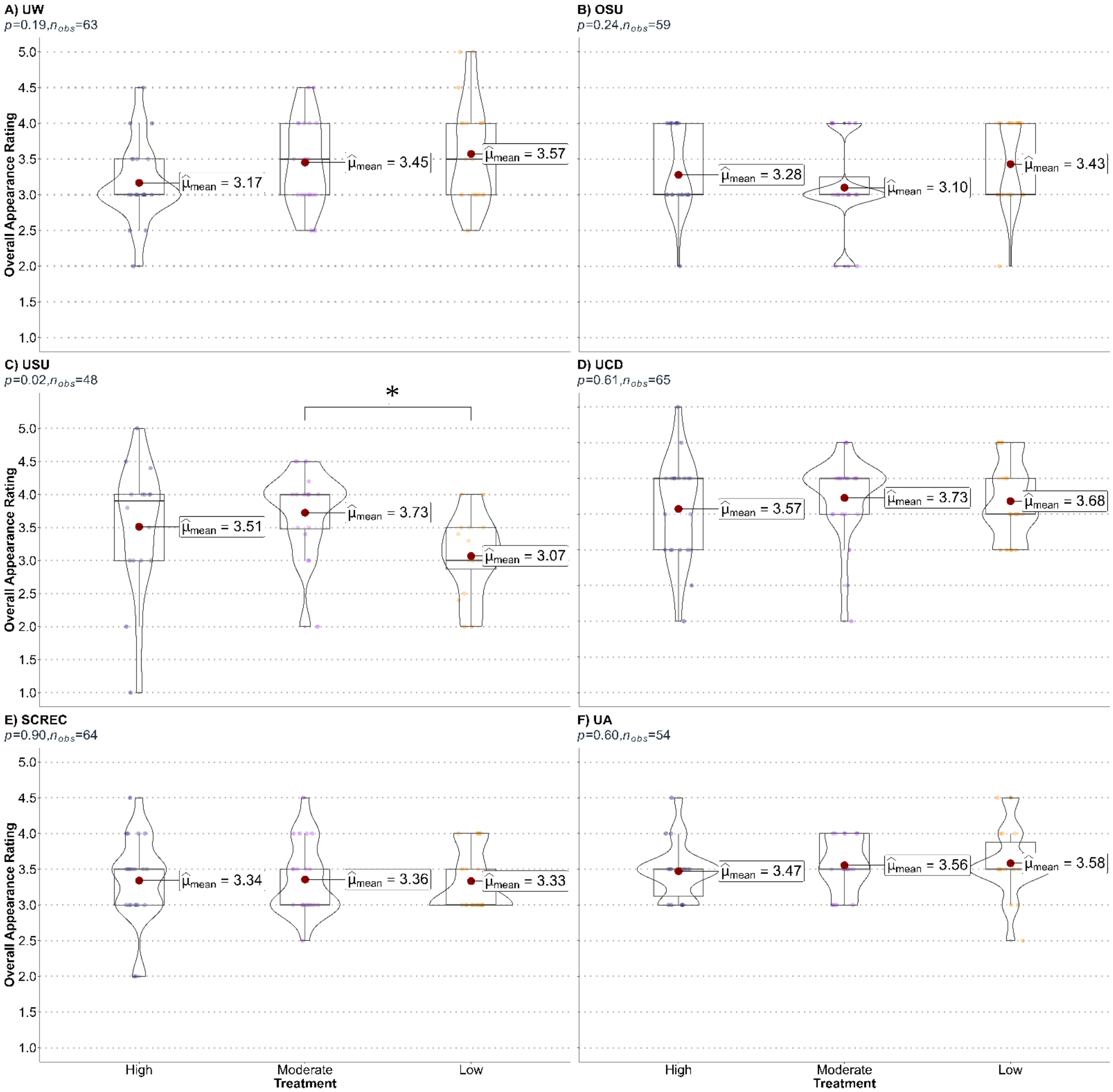

Fig. 2 Overall appearance rating distribution for each deficit treatment at each field site A) UW, B) OSU, C) USU, D) UCD, E) SCREC, and F) UA. There is a significant difference between the low and moderate treatments at the USU field site indicated by the p-value bar and "*". Reported with each plot is the p-value and the number of observations per each site (n_{obs}).

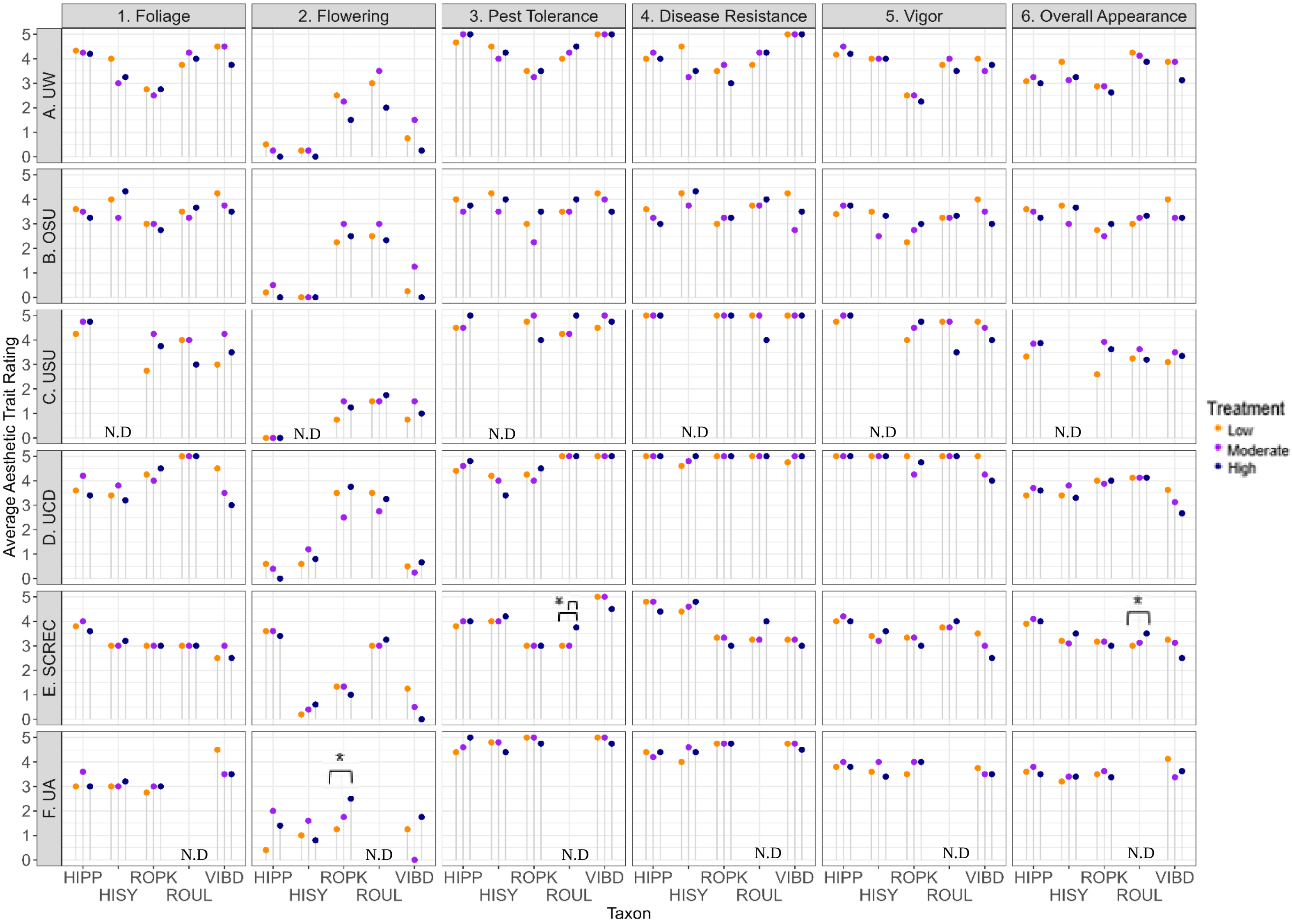

Fig. 3 Average appearance ratings for each taxon at each site A) UW, B) OSU, C) USU, D) UCD, E) SCREC, and F) UA. Treatment is indicated by the color of the dots. Significance between treatments is denoted by a significance bar and star. Taxa are broken down into their species code, HIPP is *Hibiscus syriacus* ‘Gandini Santiago’, HISY is *Hibiscus syriacus* 'ORSTHIB5x1', ROPK is *Rosa* ‘Meibenbino’, ROUL is *Rosa* ‘ChewPatout’, and VIBD is *Vitex* ‘SMVACBD’. N.D. refers to no data recorded for *Hibiscus syriacus* ‘ORSTHIB5x1’ at USU as that taxon did not survive with enough replicates, and for *Rosa* ‘Chewpatout” at UA as that taxon was not grown at that site.

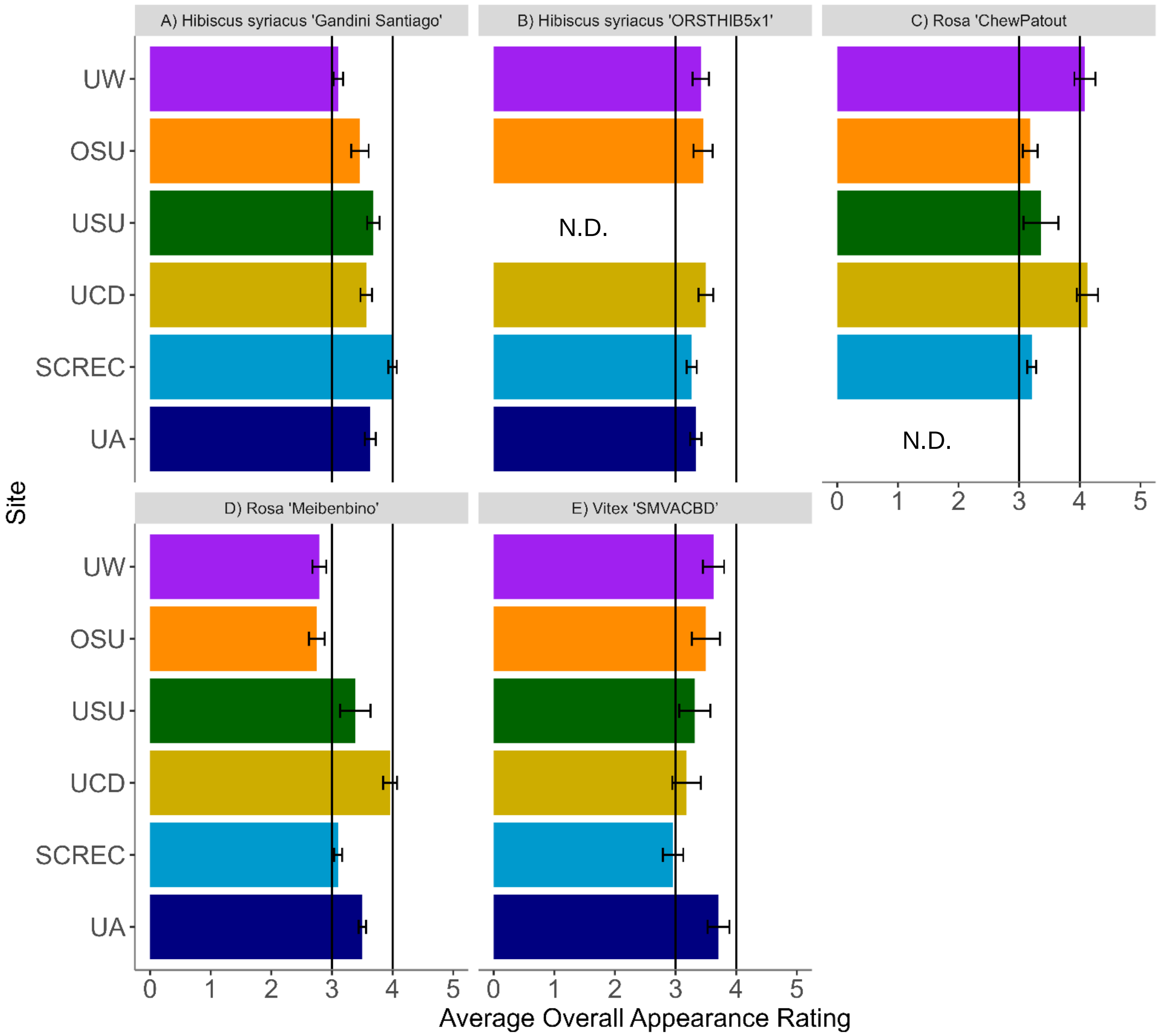

Fig. 4 Average overall appearance rating +/- one standard error reported for each taxon and site combination. Black lines indicate an overall appearance rating of 3 or 4 to highlight taxa that had an average overall appearance rating of >3 or >4. N.D. refers to no data recorded for *Hibiscus syriacus* ‘ORSTHIB5x1’ at USU as that taxon did not survive with enough replicates, and for *Rosa* ‘Chewpatout” at UA as that taxon was not grown at that site.

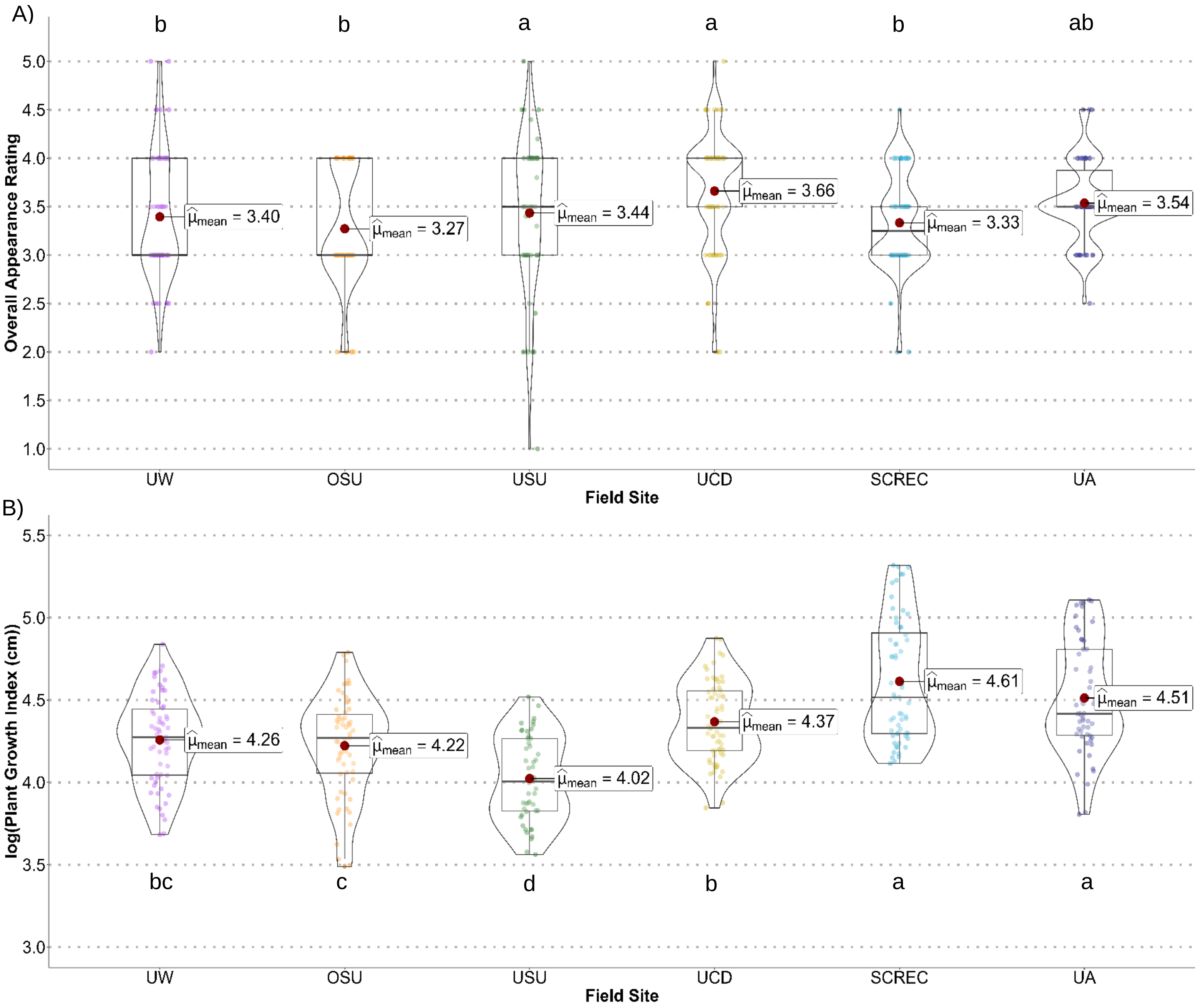

Fig. 5 A) Overall appearance rating and B) log of Plant Growth Index (PGI) distribution for each field site. Significant differences between sites for overall appearance and PGI are indicated by differing letters.

Objective 2: Leaf Physiological Parameters

Stomatal conductance and Φ_{PSII} did not vary significantly between treatments at each site (Fig. 6) when using an ANCOVA to control for light level. Φ_{PSII} did differ significantly between SCREC-UW (Tukey HSD $p < 0.01$) and SCREC-UCD (Tukey HSD $p < 0.01$) with UW and SCREC having higher Φ_{PSII} values than UCD. Stomatal conductance did not differ significantly between sites however, on average, across all taxa and treatments stomatal conductance at the UW site had a higher conductance ($\mu = 0.414$ +/- 0.0212 mol m^{-2} s^{-1}) than UCD ($\mu = 0.366$ +/- 0.0190 mol m^{-2} s^{-1}) and SCREC ($\mu = 0.326$ +/- 0.0275 mol m^{-2} s^{-1}). Within each taxon at each site, stomatal conductance and Φ_{PSII} did not vary significantly between treatments.

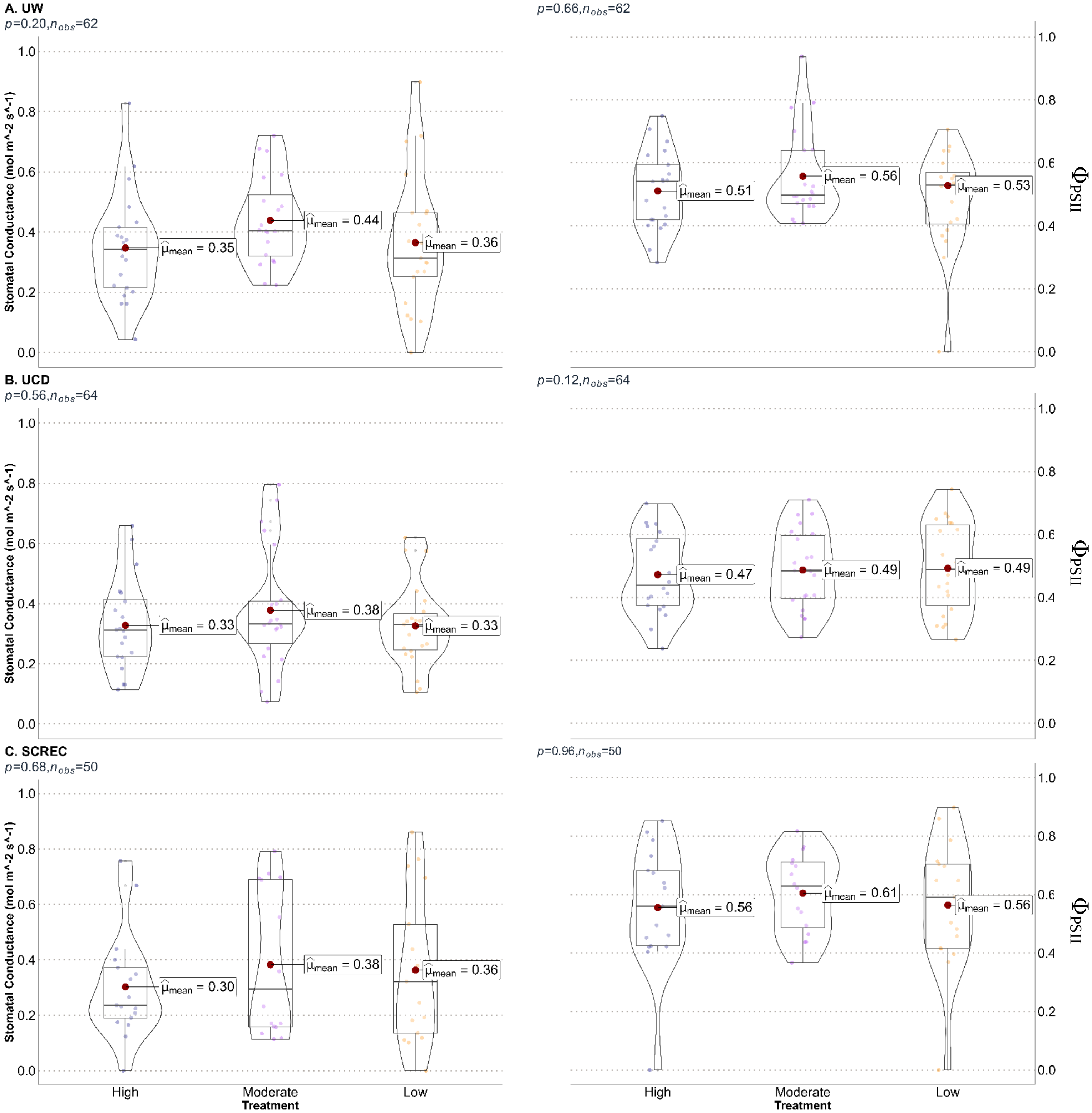

Fig. 6 Stomatal conductance (mol $m^{-2}s^{-1}$) and Φ_{PSII} distribution for each site and treatment A) UW, B) UCD, C) SCREC. Reported with each plot is the p-value and the number of observations (n_{obs}) for individual sites.

Objective 3: Comparing Aesthetic Ratings and Growth to Leaf Physiology

At the UW site comparing g_s to aesthetic and growth parameters, there was a significant, positive correlation between g_s and overall appearance (Fig.7A, r = 0.393, p =0.00158), but g_s did not correlate with PGI (Fig.7A, r = -0.199, p = 0.122). Φ_{PSII} did not correlate with PGI (Fig.7A, r = -0.171, p = 0.183) or overall appearance (Fig.7A, r = 0.0991, p = 0.443). At the UCD site, g_s did not correlate with overall appearance (Fig.7B, r = 0.167, p = 0.187) or PGI (Fig.7B, r = -0.0241, p = 0.852). Φ_{PSII} was significantly negatively correlated with overall appearance (Fig.7B, r = -0.265, p =0.0344), but not PGI (Fig.7B, r = -0.214, p = 0.0889). At the SCREC site, g_s was not correlated to overall appearance (Fig.7C, r = 0.00338, p = 0.981) or PGI (Fig.7C, r = -0.0285, p = 0.844). Φ_{PSII} was significantly positively correlated with overall appearance (Fig.7C, r = 0.402, p = 0.00379), but not with PGI (Fig.7C, r = 0.264, p = 0.0635). A higher Φ_{PSII} was generally negatively correlated with flowering score for all sites.

There was a significant difference in soil moisture between the high and low water treatments ($p < 0.01$) at UW. The high-water treatment had on average a higher soil moisture over time, even when irrigated at the same time, than the low water treatment (Fig. 8).

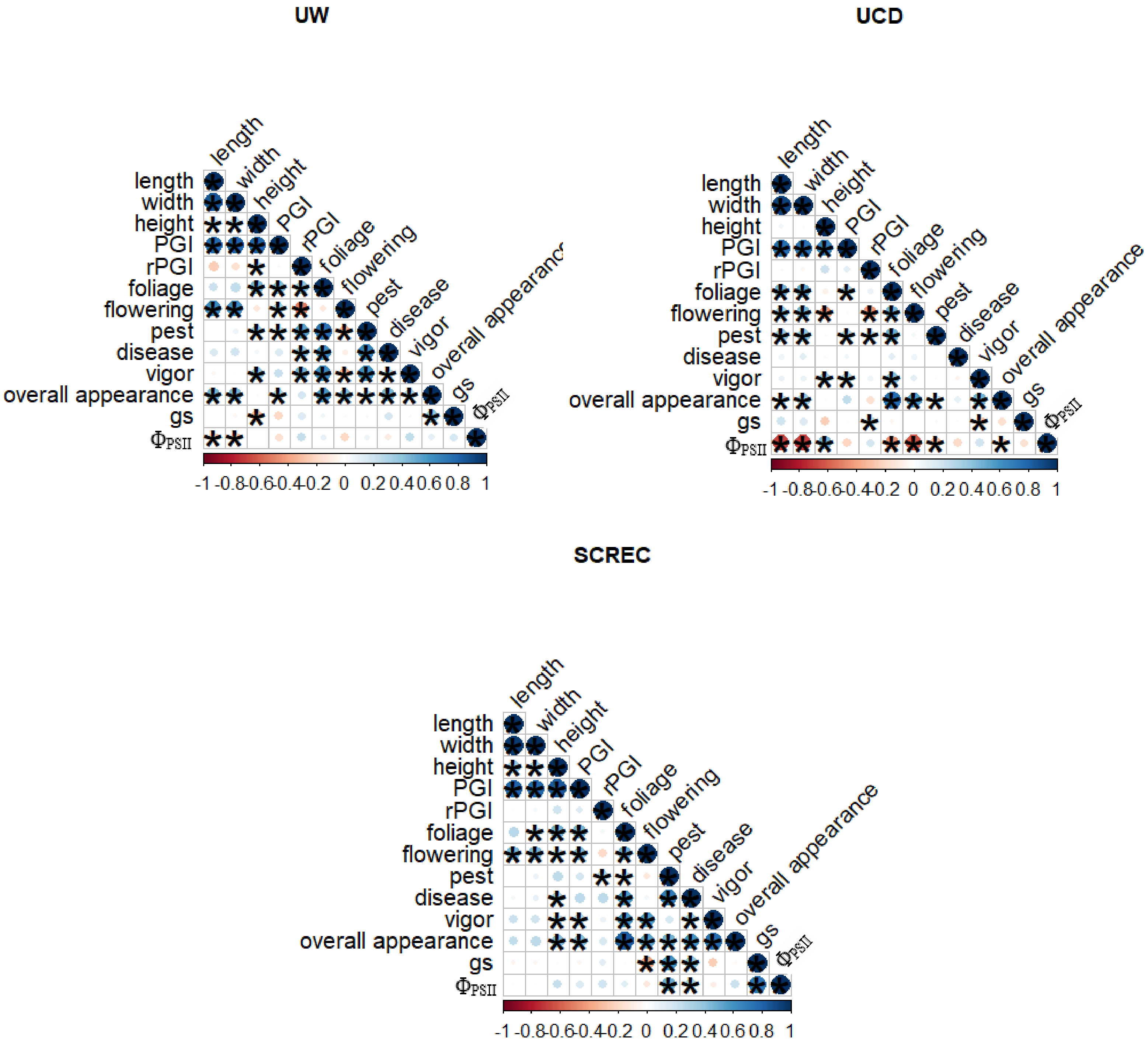

Fig. 7 Correlation plot between all aesthetic ratings, growth parameters, and physiological parameters measured at A) UW, B) UCD, and C) SCREC. Color indicates the direction of the relationship; red is a negative relationship and blue is a positive relationship. Color intensity and dot size represent the strength of the correlation; a darker color and larger dot is a stronger relationship. Relationships marked as “*” indicate significant p-values (<0.05). g_s refers to stomatal conductance.

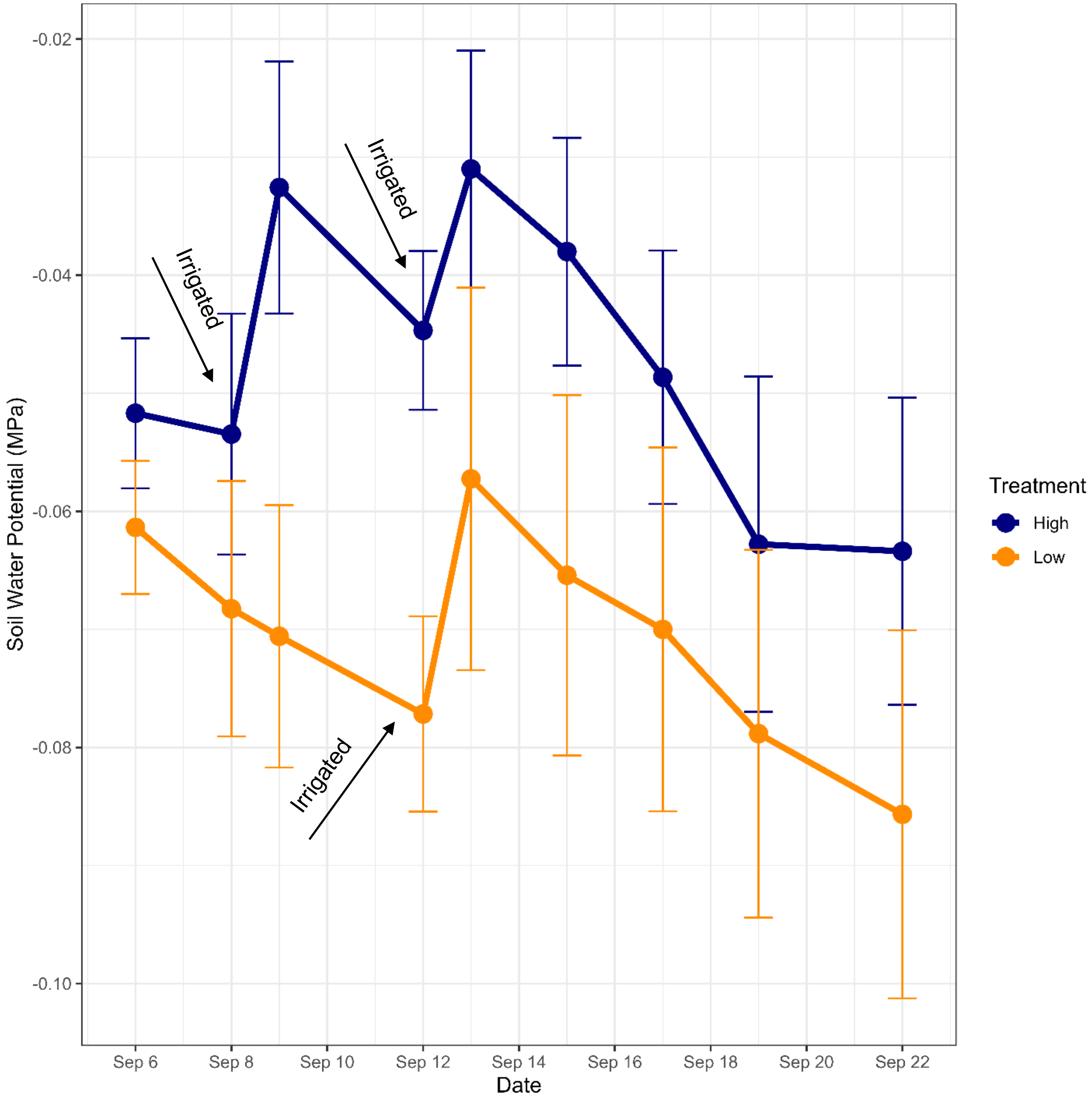

Fig. 8 Average soil water potential (MPa) measured over time in September at UW showing the differences in soil moisture between high and low water treatments. Error bars indicate +/- one standard error. Irrigation happened for the high treatment on September 8th and 12th, and irrigation happened for the low treatment on September 12th highlighted by black arrows.

Discussion

We assessed aesthetic quality, growth, and leaf physiology of five different landscape plant cultivars in three deficit irrigation treatments at six different institutions across the Western U.S. Measuring both aesthetic parameters and leaf physiology helped to give a more complete picture of plant health and performance between water deficit treatments. These parameters were assessed at the taxa and site level (within and between sites).

Objective 1: Aesthetic Qualities

When all data were pooled together across taxa, plant aesthetic performance was not affected by water deficit treatments at each field site. One exception to this was at the USU site where overall appearance ratings were impacted by treatment, and the plants grown in the moderate treatment had significantly higher overall appearance scores than the low treatment. Differences in appearance ratings between treatments for each taxon at USU, however, were not seen. This may be because when comparing differences in treatment at the site level, the taxa were pooled together, thus all the variation between taxa were combined in each treatment expressed in only one high, moderate, and low treatment for the entire site. Each taxon has its own growth habits and tolerance to water deficit so it would be hard to compare performance between taxa. Only when separating taxa within each site are we able to see if there was a treatment effect because then it would be a comparison of plants of the same cultivar. Therefore, basing performance of appearance may be more appropriate at the taxa level. This would mean that taxa at USU could be watered at the lowest frequency and still maintain aesthetic value.

When each taxon was analyzed separately, *Rosa* ‘ChewPatout’ did perform better in overall appearance in the high versus low treatment at SCREC, but this was not seen in other taxa at this site or other sites (Fig. 3). Some studies report differences in aesthetic qualities between water deficit treatments for some taxa and no differences for other taxa (Zollinger et al., 2006; Harp et al., 2019; Reid and Oki, 2016; Sapkota et al., 2023). For example, Sapkota et al. (2021) found that visual rating, considering plant spread, color, and vigor, was significantly reduced in the low water treatment for six out of eight landscape groundcover plants tested. Additionally, Reid and Oki (2016) found that *Rosa* 'Korbin' had the best appearance rating scores in the moderate treatment whereas *Mimulus* 'Curious Georgie Boy' showed best appearance in the low water treatment. Paine et al. (1992) reported no difference in visual rating, based on plant vigor, for all three taxa tested between water deficit treatments. There were not many treatment effects on appearance ratings for each taxon, therefore variations in these ratings between sites could be attributed to the wide range of climatic conditions and soil differences. For instance, overall appearance ratings at UCD were significantly higher than at UW, OSU, and SCREC (fig. 5). The UCD site also had a high soil water holding capacity compared to those three sites, which may have contributed to higher overall appearance if their plants were able to have access to water for a longer period. At least for this set of taxa, when comparing overall appearance between sites, the average score is still in the 'OK' (3) to 'very nice (4) ranking. Regardless of differences between sites, the data show that overall appearance and the other aesthetic parameters were not significantly affected by treatment, more importantly meaning that the frequency of irrigation can be reduced while maintaining aesthetic quality.

Objective 1: Growth

Our results show that treatment did have a significant effect on growth across taxa at each site with the higher of the two treatments compared having greater growth. However, this was not demonstrated for all taxa at all sites. This varies from Paine et al. (2006), who reported their taxa's growth was not affected by water deficit treatment. Similar to the aesthetic ratings, differences in growth between sites could be attributed to variations in climate and soil as precipitation, ETo, and temperature varied greatly. For instance, the UA site's soil had one of the highest water holding capacities between sites and plants at that site had the second highest PGI. In one study, shoot growth was severely impacted by a low water treatment in *Rhododendron* cv. Hoppy, causing the plants to remain small throughout the rest of the growing season (Cameron et al., 2008). Additionally, Zollinger at el. (2006), who reported no treatment effect on aesthetic qualities, found that shoot dry weight decreased for each taxon in increasing water deficit conditions. However, Reid and Oki (2016) in their trials found that overall rPGI was not affected by treatment for most of the taxa tested. In our trials, we found more differences in growth between treatments than aesthetic parameters. This may be because even if growth was affected by treatment, that does not necessarily mean that aesthetic appearance would be affected. Even if a plant is not pushing out new growth, that does not mean that foliage quality, for example, would be unacceptable. Each taxon has its own requirements for growth and physiological functions that make it better able to tolerate stress in different climates.

Objective 2: Physiological Parameters

Overall, treatment was not a significant influence on stomatal conductance within and between field sites, showing that decreasing irrigation frequency did not unreasonably stress the plants. In increased drought conditions, it would be expected that g_s would decrease to conserve water (Murata and Mori, 2013; Yang et al., 2021) as one primary response for plants experiencing water deficit is to close their stomata (Chaves et al., 2002; Matthews et al., 2017). However, g_s was not affected by treatment, indicating that the plants were not stressed to the point where their stomata were closed to conserve water. Additionally, Φ_{PSII} was not significantly influenced by treatment at each site, though it did vary significantly between sites with SCREC having a higher photon yield (Fig. 6). The differences in Φ_{PSII} between sites could be due to differences in light intensity and length influencing photosynthesis. This differs from studies that have shown a decrease in Φ_{PSII} with increasing water deficit (Huang et al., 2013; Guo et al., 2016; Yang et al., 2023). Even when factoring in the influence of light on g_s and Φ_{PSII} at all sites, there was no significant difference in treatment. This demonstrates that based on Φ_{PSII} levels, similar to g_s, the plants were not severely stressed when watered less frequently even across sites. Considering no strong differences physiologically in response to less water in this set of taxa, this has significant implications for reducing irrigation usage. One thing to keep in mind is that this reflects only three of the six sites and does not encompass all the climatic variability. Therefore, we cannot generalize this effect for all sites and is one limitation to this analysis.

Soil moisture did vary significantly between treatments measured by the soil moisture sensors at UW, and there were clear spikes in soil moisture when the irrigation events happened (Fig. 8). This confirmed that the irrigation system was working properly, and the plants were receiving the assigned treatments. Therefore, even though the plants were receiving the specified treatment, we still saw no strong treatment effect on the parameters measured. However, we did see differences between sites in almost all parameters measured. Each site has a different soil texture, therefore the water holding capacity and plant available water levels will be different. For example, UW site has sandier soil compared to UCD which has clayey soil. Water drains faster through sand because it has larger pore spaces compared to clay, which holds onto water for longer. In the context of plants, the difference in water holding capacity of the soil means differences in plant available water (Zhang et al., 2021). This can also vary on a small-scale within the same site. For example, at UW the soil texture ranged from silt loam, to sand, to loamy sand. Differences in soil texture within and between sites affect how much and how long water is available for plants. This could be one reason why we saw differences in aesthetic ratings and growth between sites but not many significant treatments effects.

Objective 3: Comparing Aesthetic Ratings and Growth to Leaf Physiology

The connection between g_s and overall appearance was not very strong across sites but was significant at UW (Fig. 7). This is interesting because g_s is inherently tied to photosynthesis through leaf gas exchange which influences overall plant health (Lawson and Morison, 2004) and I would expect g_s to correlate more strongly with overall appearance. Additionally, g_s was not significantly different between sites yet UW was the only site that had a significant correlation between g_s and overall appearance. This may be due to plants not showing significant signs of stress based on g_s, so overall appearance was not affected as much. Φ_{PSII} did show a strong correlation to overall appearance at SCREC and UCD. This stronger relationship compared to correlations to g_s may be due to Φ_{PSII}'s relationship to photosynthesis, which has a more direct link to overall plant health.

Generally, there was no strong correlation between growth parameters and g_s across sites, even though conductance values indicated that stomata were open. Φ_{PSII} on the other hand showed more negative, significant correlations with growth parameters across sites. This is interesting because with a higher quantum yield and efficiency of PSII in photosynthesis, there would be more resources and energy for growth. However, even with a higher quantum yield the plants may have decreased energy input to shoot growth to focus on root growth to capture more water deep in the soil. This is one response to water deficit to increase the chances of finding water (Poorter et al., 2012; Zlatev and Lidon, 2012). For example, Eziz et al. (2017) found that plants increase root mass instead of shoot mass when under water deficit conditions. This may also be one reason why we saw reduced growth in the low water treatment. Overall, plant performance was not significantly impacted by treatment aesthetically or physiologically.

Limitations and Future Study

In the future, more taxa should be tested to increase the knowledge of landscape plant performance in different regions since there is limited data-driven documentation of water-efficient taxa. This study was limited to one field season, but in the future, taxa should be tested for a longer period to understand aesthetic performance and growth in reduced irrigation conditions, as in Harp et al. (2019). Seasons can vary from year to year even at the same site, therefore assessing plants for only one year may not effectively capture plant responses to water deficit. These taxa were chosen as being able to grow in each site’s growing zone. This means that each plant should be able to grow at each site in the right conditions, but with climate change projected to increase temperatures and droughts, growing zones will also change (Matthews et al., 2018). Our study does not account for taxa that would be more regionally adapted, but this could be a topic for future studies. Each site followed the same methods to set up their plot, but there are inevitably differences between sites. For example, at UW the plot was not completely level so there was standing water in that area for much of Spring 2022 where coincidentally there was a higher amount of mortality than other parts of the plot. Additionally, the history of each plot could have influenced plant performance. For instance, the UW site was originally a grass field, and it was hard to keep weeds from growing in the plot while the UCD site was already a test plot before being used for this study, so weeds were not a significant problem. An abundance of weeds can affect soil available for the study plants (Zhang et al., 2021).

While our study tried to reduce confounding variables by using a completely randomized design (CRD), a randomized complete block design (RCBD) could improve the precision of statistical analysis. Each block would have one representative of each taxon and treatment combination to reduce the influence of external variables even more within and between sites. Conducting this experiment in the field replicates more real-world conditions for the plants, but it also introduces a lot of external variables. However, this is more meaningful than conducting the experiment in a greenhouse as these plants are meant to be enjoyed in landscapes. Measuring physiological parameters only one time in the growing season may not give an accurate picture of plant responses to water deficit over the entire field season. In the future, these parameters should be measured over the whole field season.

This research attempted to test different taxa across the Western U.S. in their ability to withstand various levels of water deficit. While there may be variation in plant performance between sites, and this is expected, these taxa performed well in aesthetic quality even when watered less frequently. This is notable considering some sites only watered the plants in the low treatment 1-4 times throughout the field trial compared to the high treatment that was watered 9-18 times. On the other hand, growth was impacted by treatment and plants may have put more energy into belowground versus aboveground growth to capture more water. The physiological measurements showed the plants were not experiencing significant stress.

Conclusions

Our results showed that taxa grown in the moderate and low-water treatment performed just as well aesthetically as those grown in the high-water treatment. However, growth was generally significantly higher in the high compared to low water treatment. Between sites, UW, OSU, and USU did not have significantly higher overall appearance compared to UCD, SCREC, and UA. Considering the leaf physiological responses, our findings differed from our hypothesis that g_s and Φ_{PSII} would be higher in the high treatment for all taxa, and only Φ_{PSII} varied between sites. Additionally, higher g_s and Φ_{PSII} did not necessarily correlate with higher aesthetic ratings and growth.

These findings can be informative for growers and for consumers to help reduce irrigation waste and to plan for a less predictable climate future. For example, growers may be able to market most of the taxa tested as water-wise, helping consumers make informed decisions about plant water needs. Additionally, horticulturalists can promote and use these taxa as well to reduce their irrigation usage. Consumers can use this information to reconsider their irrigation techniques and the water needs of other plants in their yard, not just the taxa tested here. Informing and educating consumers is an important part of trying to reduce irrigation. For instance, when given a choice between home landscapes with increasingly water-efficient features, 55% of consumers preferred the most water-efficient yard (Hayden et al., 2015). However, consumer behaviors do not fully reflect this, as only 10% of homeowners surveyed reported their yards looking like the water-wise option (Hayden et al., 2015). If consumers are aware of how they can create a more water-efficient yard through resources such as this study, then the impact of conserving irrigation water will be that much larger.

This study also bridges the gap between only considering physiology (Chapman and Augé, 1994; Huang and Gao, 1999) or only visible traits (Harp et al., 2019) when assessing potential water stress in landscape plants. Assessing both internal and external health gives a more complete picture of plant health and a plant's ability to tolerate water deficit while still outwardly performing well. Studies that tested drought tolerance of taxa in one area are informative to that specific region (Huang and Gao, 1999; Zollinger et al., 2006; Harp et al., 2019), but may not be applicable in a wider scope. With climate change shifting planting zones and precipitation patterns, studies such as this that test taxa over a larger area will help determine which taxa will grow well in areas they might not have in the past.

As droughts and water consumption increase in the Western U.S. (Flint et al., 2018; Ali et al., 2022), it is essential to target areas where water conservation is easy to achieve. People will always want attractive landscapes because they increase overall health and bring joy (Dunnett and Qasim, 2000; Hall and Dickson, 2011). Therefore, determining water-efficient, aesthetically pleasing taxa across the Western U.S. will satisfy consumers while reducing the need for frequent irrigation.

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Supplemental Information:

Table S1 Criteria for plant aesthetic ratings. Each aesthetic quality is broken up into ratings 1 (dead/dying) to 5 (excellent). Plants that were not flowering were given a rating of zero. Overall appearance could be scored in half point increments.

RATING	5	4	3	2	1
Foliage	Perfect to excellent; plant is in full leaf with no signs (1% or less) of leaf burn, disease or insect damage, and leaves are distributed uniformly in an appealing shape for the genus/species.	Very nice. Same as 5 except for minor tip burn, edge damage or other minor damage to only a few leaves (1-10%) that does not much affect the appearance (not noticeable from 3-4').	Acceptable; may have non-uniform distribution of leaves or minor damage to 11- 25% of leaves that is less evident from a distance.	Unacceptable; loss of leaves or moderate damage than 25% of leaves; unattractive; plant is declining and may not recover; may be extremely non-uniform.	Completely unacceptable; close to dead.
Flowering	Full, glorious bloom; 80-100% of plant's potential for bloom coverage is open	61-80% of plant in bloom	41-60% of plant in bloom	21-40% of plant in bloom	1 bloom open to 20% in bloom
Pest Tolerance/ Disease Resistance	No visible damage (1% or less) especially from 3-4' away.	Minor to moderate damage to one or two leaves or stems, or very minor damage to a few leaves (1-25%) Not noticeable from 3-4 ft.	Minor damage to many of the leaves or flowers (25-50%); appearance still acceptable from a distance of 3-4'.	Major damage; appearance unacceptable (51-75%).	Severely damaged and probably dying (>75% affected).
Vigor	Pushing out new growth from every growing point.	Pushing out new growth from several growing points.	Plant is surviving and healthy, but not noticeably pushing out new growth.	Plant is very small for the species or is declining; dead/dying branches or leaves present.	Plant is barely alive; close to death.
Overall Appearance	An impressive plant; flowers (if present), leaves, the shape and condition of the plant are all very appealing. It has the WOW factor that makes it an attractive garden plant***, even if each individual factor isn't perfect.***	A very good plant; maybe a 5 when in bloom, or just a very nice species that is not quite at its prime or just lacks the WOW factor. Many foliage plants fall here, while exceptional ones may be 5s.	Acceptable but nothing special; may be past or not quite to its prime; might be better if more uniform; may be described as an 'okay' plant.	Unacceptable for any of the above reasons.	Completely unacceptable and not likely to improve.

Table S2 The number of irrigation events and liters of water applied over 0.39 m^3 between April-September for UCD, SCREC, and UA, and between June-September for UW, USU, and OSU for each water deficit treatment and study site.

	Low treatment		Medium Treatment		High Treatment	
Site	Number of Irrigation Events	Liters of water applied per 0.39 m^3	Number of Irrigation Events	Liters of water applied per 0.39 m^3	Number of Irrigation Events	Liters of water applied per 0.39 m^3
UW	3	43.2	6	85.9	10	143.5
OSU	2	78.4	5	196.5	9	353.6
USU	1	35.9	4	143.8	8	287.3
UCD	4	146.9	10	367.6	15	551.2
SCREC	4	117.7	11	324.0	18	530.3
UA	2	78.0	9	350.9	15	584.8

Table S3 Trigger point of Eto (cm) accumulated when a treatment would need to be irrigated, number of pulses of water, the length of one pulse (min), and the total time water was applied to the plants (min) for each site. NA values for number of pulses, run time per pulse, and total run time for UA are recorded because that site irrigated a little differently than the other sites.

Site	Trigger point (cm Eto)	Number of Pulses	Run Time per Pulse (min)	Total Irrigation Time (min)
UW	1.83	4	27	108
OSU	5.00	4	74	294
USU	4.57	3	90	270
UCD	4.67	4	46	164
SCREC	3.56	4	67	268
UA	5.00	NA	NA	NA

Table S4 The taxon that scored the highest in each aesthetic rating category at each field site with corresponding average rating score and standard error. Abbreviations are used in place of taxa names: HIPP is *Hibiscus syriacus* ‘Gandini Santiago’, HISY is *Hibiscus syriacus* 'ORSTHIB5x1', ROPK is *Rosa* ‘Meibenbino’, ROUL is *Rosa* ‘ChewPatout’, and VIBD is *Vitex* ‘SMVACBD’.

Site	Foliage Quality	Flowering	Pest Tolerance	Disease Resistance	Vigor	Overall Appearance
UW	HIPP 4.27+/-0.118	ROUL 2.83+/-0.271	VIBD 5.0+/-0.00	VIBD 5.00+/-0.00	HIPP 4.27+/-0.118	ROUL 4.08+/-0.172
OSU	VIBD 3.83+/-2.97	ROUL 2.63+/-0.310	VIBD 3.92+/-0.193	VIBD 4.09+/-0.163	HIPP 3.62+/-0.180	VIBD 3.50+/-0.230
USU	HIPP 4.58+/-0.148	ROUL 1.58+/-0.398	VIBD 4.75+/-0.131	ROPK 5.00+/-0.00	HIPP 4.92+/-0.0833	HIPP 3.68+/-0.103
UCD	ROUL 5.00+/-0.00	ROPK 3.25+/-0.305	VIBD 5.00+/-0.00	ROPK 5.00+/-0.00	ROUL 5.00+/-0.00	ROUL 4.13+/-0.175
SCREC	HIPP 3.80+/-0.107	HIPP 3.53+/-0.133	VIBD 4.83+/-0.167	HIPP 4.67+/-0.126	HIPP 4.07+/-0.153	HIPP 4.00+/-0.0690
UA	VIBD 3.83+/-0.241	ROPK 1.83+/-0.207	ROPK & VIBD 4.92+/-0.0833	ROPK 4.75+/-0.131	HIPP 3.87+/-0.0909	VIBD 3.71+/-0.179

Table S5 Each site and taxa paring treatment effect with resulting significance value reported P-value < 0.05 = * in greyed cells. The treatments that differed were reported with corresponding post-hoc p-value. The treatment indicated first scored higher or had higher growth. 1 indicates that the ratings were the same for each plant in that taxon, thus there was no difference to be found.

Site	Taxon	Foliage	Flowering	Pest Tolerance	Disease Resistance	Vigor	Overall Appearance	PGI	rPGI
UW	HIPP	0.888	0.196	0.200	0.889	0.489	0.520	0.639	0.262
	HISY	0.815	0.5769	0.2946	0.08247	NA	0.05201	0.591	0.361
	ROPK	0.503	0.0583	0.295	0.294	0.295	0.602	0.611	0.395
	ROUL	0.832	0.310	0.931	0.306	0.730	0.698	0.859	0.300
	VIBD	0.153	0.256	NA	1	0.566	0.132	0.066	0.037*
OSU	HIPP	0.594	0.584	0.235	0.624	0.771	0.594	0.167	0.594
	HISY	0.128	NA	0.302	0.286	0.188	0.0905	0.396	0.0905
	ROPK	0.740	0.664	0.0774	0.863	0.428	0.295	0.930	0.295
	ROUL	0.566	0.711	0.343	0.892	0.978	0.511	0.416	0.510
	VIBD	0.665	0.0694	0.266	0.448	0.134	0.267	0.672	0.267
USU	HIPP	0.285	1	0.356	1	0.368	0.0582	0.427	0.479
	HISY	NA	NA	NA	NA	NA	NA	NA	NA
	ROPK	0.147	0.551	0.239	1	0.343	0.116	0.320	0.362
	ROUL	0.462	0.964	0.145	0.368	0.594	0.717	0.251	0.297
	VIBD	0.280	0.667	0.295	1	0.578	0.776	0.0937	0.478
UCD	HIPP	0.217	0.171	0.703	1	1	0.458	0.273	0.452
	HISY	0.337	0.180	0.340	0.581	1	0.193	0.399	0.225
	ROPK	0.566	0.175	0.566	1	0.270	0.993	0.648	0.0722
	ROUL	1	0.7973	1	1	1	0.810	0.740	0.508
	VIBD	0.297	0.5658	1	0.420	0.349	0.275	0.841	0.480
SCREC	HIPP	0.311	0.779	0.368	0.326	0.842	0.497	0.926	0.699
	HISY	0.368	0.459	0.368	0.459	0.459	0.132	0.351	0.315
	ROPK	1	0.472	1	0.472	0.472	0.472	0.666	0.751
	ROUL	1	0.3679	0.0256*	0.0639	0.5769	0.0168*	0.960	1
	VIBD	0.526	0.0868	0.368	0.774	0.0639	0.190	0.484	0.0489*
UA	HIPP	0.136	0.0870	0.282	0.756	0.584	0.392	0.0497*	1
	HISY	0.368	0.268	0.638	0.141	0.141	0.739	0.310	1
	ROPK	0.368	0.0475*[d]	0.3679	1	0.111	0.253	0.340	1
	VIBD	0.195	0.0825	0.368	0.709	0.730	0.212	0.594	1

[a] significance between high and low treatments (*p* = 0.0414)

Table S6 Average stomatal conductance (mol $m^{-2}s^{-1}$) and Φ_{PSII} for each taxon and site combination broken up between treatments reported +/- se. Stomatal conductance is shown in a blue gradient binned in 0.10 (mol $m^{-2}s^{-1}$) increments from no color to dark blue. Φ_{PSII} is shown in a green gradient binned in 0.10 (Φ) increments from no color to dark green. Taxa are broken down into their species code, HIPP is *Hibiscus syriacus* 'Gandini Santiago', HISY is *Hibiscus syriacus* 'ORSTHIB5x1', ROPK is *Rosa* 'Meibenbino', ROUL is *Rosa* 'ChewPatout', and VIBD is *Vitex* 'SMVACBD'.

Site	Taxon	Stomatal Conductance (mol $m^{-2}s^{-1}$)			Φ_{PSII}		
		High	Moderate	Low	High	Moderate	Low
UW	HIPP	0.24 ± 0.039	0.31 ± 0.041	0.14 ± 0.042	0.63 ± 0.037	0.61 ± 0.11	0.48 ± 0.099
	HISY	0.39 ± 0.013	0.59 ± 0.063	0.42 ± 0.069	0.57 ± 0.073	0.73 ± 0.035	0.82 ± 0.19
	ROUL	0.42 ± 0.069	0.45 ± 0.027	0.41 ± 0.039	0.50 ± 0.055	0.54 ± 0.037	0.53 ± 0.026
	ROPK	0.28 ± 0.041	0.35 ± 0.023	0.28 ± 0.032	0.42 ± 0.046	0.45 ± 0.021	0.40 ± 0.016
	VIBD	0.32 ± 0.13	0.50 ± 0.10	0.65 ± 0.13	0.40 ± 0.041	0.46 ± 0.019	0.41 ± 0.055
UCD	HIPP	0.16 ± 0.020	0.20 ± 0.055	0.21 ± 0.053	0.57 ± 0.028	0.60 ± 0.022	0.62 ± 0.044
	HISY	0.31 ± 0.090	0.42 ± 0.084	0.31 ± 0.041	0.50 ± 0.13	0.60 ± 0.044	0.63 ± 0.0098
	ROUL	0.27 ± 0.023	0.37 ± 0.021	0.28 ± 0.025	0.32 ± 0.041	0.35 ± 0.030	0.33 ± 0.032
	ROPK	0.33 ± 0.041	0.33 ± 0.031	0.33 ± 0.049	0.36 ± 0.024	0.40 ± 0.033	0.34 ± 0.017
	VIBD	0.57 ± 0.068	0.61 ± 0.13	0.53 ± 0.066	0.41 ± 0.026	0.43 ± 0.042	0.47 ± 0.018
SCREC	HIPP	0.35 ± 0.023	0.35 ± 0.099	0.41 ± 0.046	0.75 ± 0.041	0.66 ± 0.036	0.77 ± 0.071
	HISY	0.55 ± 0.099	0.69 ± 0.038	0.69 ± 0.082	0.72 ± 0.046	0.73 ± 0.030	0.70 ± 0.025
	ROUL	0.21 ± 0.014	0.16 ± 0.027	0.16 ± 0.018	0.45 ± 0.019	0.46 ± 0.045	0.42 ± 0.029
	ROPK	0.18 ±0 .021	0.14 ± 0.016	0.15 ± 0.046	0.46 ± 0.034	0.41 ± 0.024	0.45 ± 0.019

Table S7 P-values of each site and trait combination compared to treatment. Significant differences in treatment are reported P-value < 0.05 *, and < 0.01 **.

	Site					
Parameter	UW	OSU	USU	UCD	SCREC	UA
Foliage	0.517	0.399	0.0895	0.523	0.590	0.739
Flowering	0.146	0.344	0.752	0.935	0.894	0.190
Pest Tolerance	0.732	0.103	0.578	0.957	0.881	0.873
Disease Resistance	0.836	0.468	0.392	0.365	0.964	0.804
Vigor	0.810	0.817	0.293	0.122	0.765	0.220
Overall Appearance	0.186	0.236	0.0175[a]	0.607	0.898	0.605
PGI (cm)	0.672	0.549	0.280	0.699	0.950	0.122
rPGI	0.474	0.663	0.582	0.787	0.467	NA
Length (cm)	0.979	0.554	0.513	0.938	0.994	0.0784
Width (cm)	0.846	0.557	0.914	0.812	0.993	0.0276[c]
Height (cm)	0.580	0.704	0.0195[b]	0.541	0.923	0.481

[a] significance between moderate and low treatments (*p* = 0.0179)
[b] significance between high and low treatments (*p* = 0.0171)
[c] significance between moderate and low treatments (*p* = 0.0219)

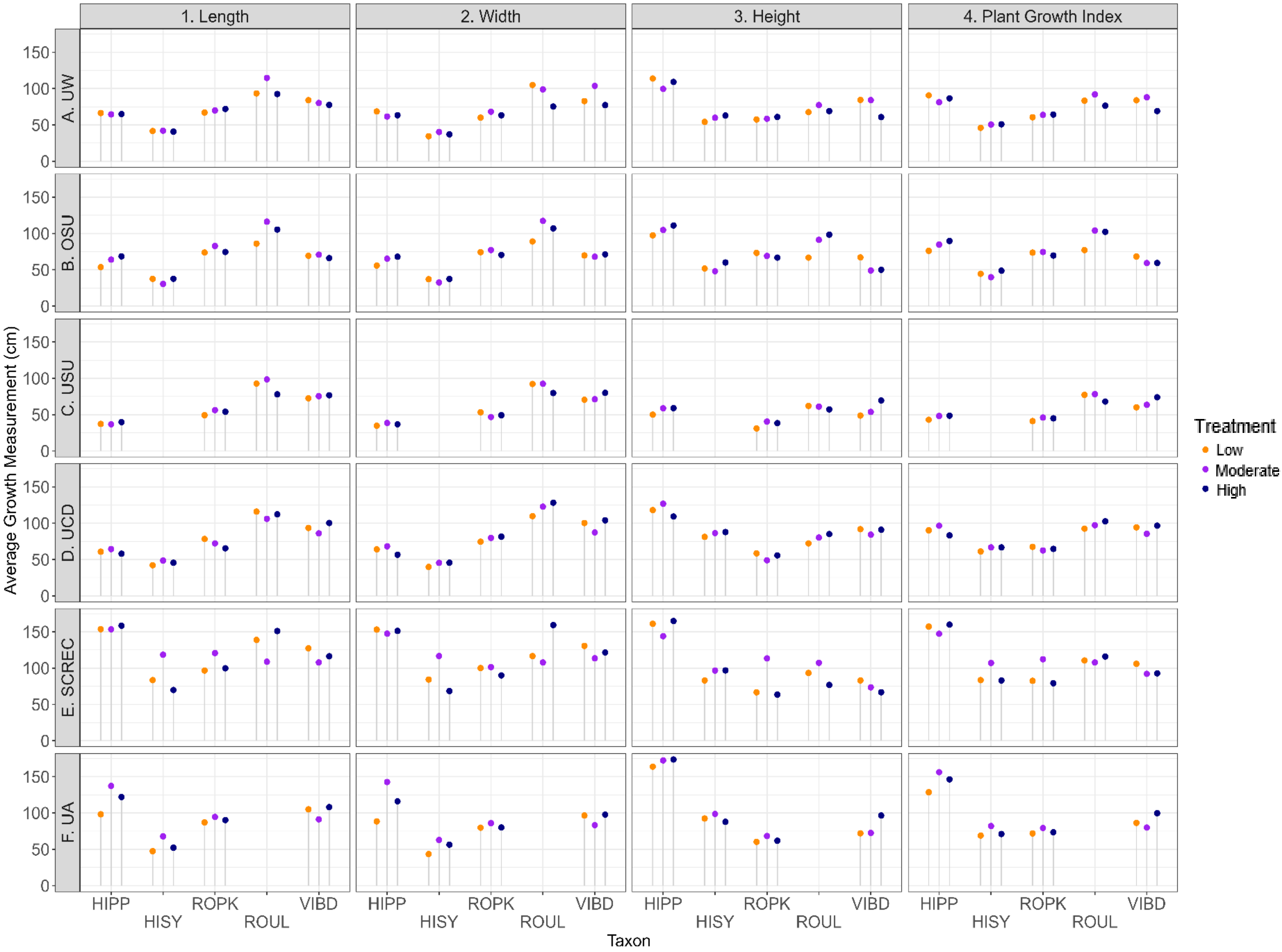

Fig. S1 Average growth measurement for each taxon at each site A) UW, B) OSU, C) USU, D) UCD, E) SCREC, and F) UA. Treatment is indicated by the color of the dots. Taxa are broken down into their species code, HIPP is *Hibiscus syriacus* 'Gandini Santiago', HISY is *Hibiscus syriacus* 'ORSTHIB5x1', ROPK is *Rosa* 'Meibenbino', ROUL is *Rosa* 'ChewPatout', and VIBD is *Vitex* 'SMVACBD'.

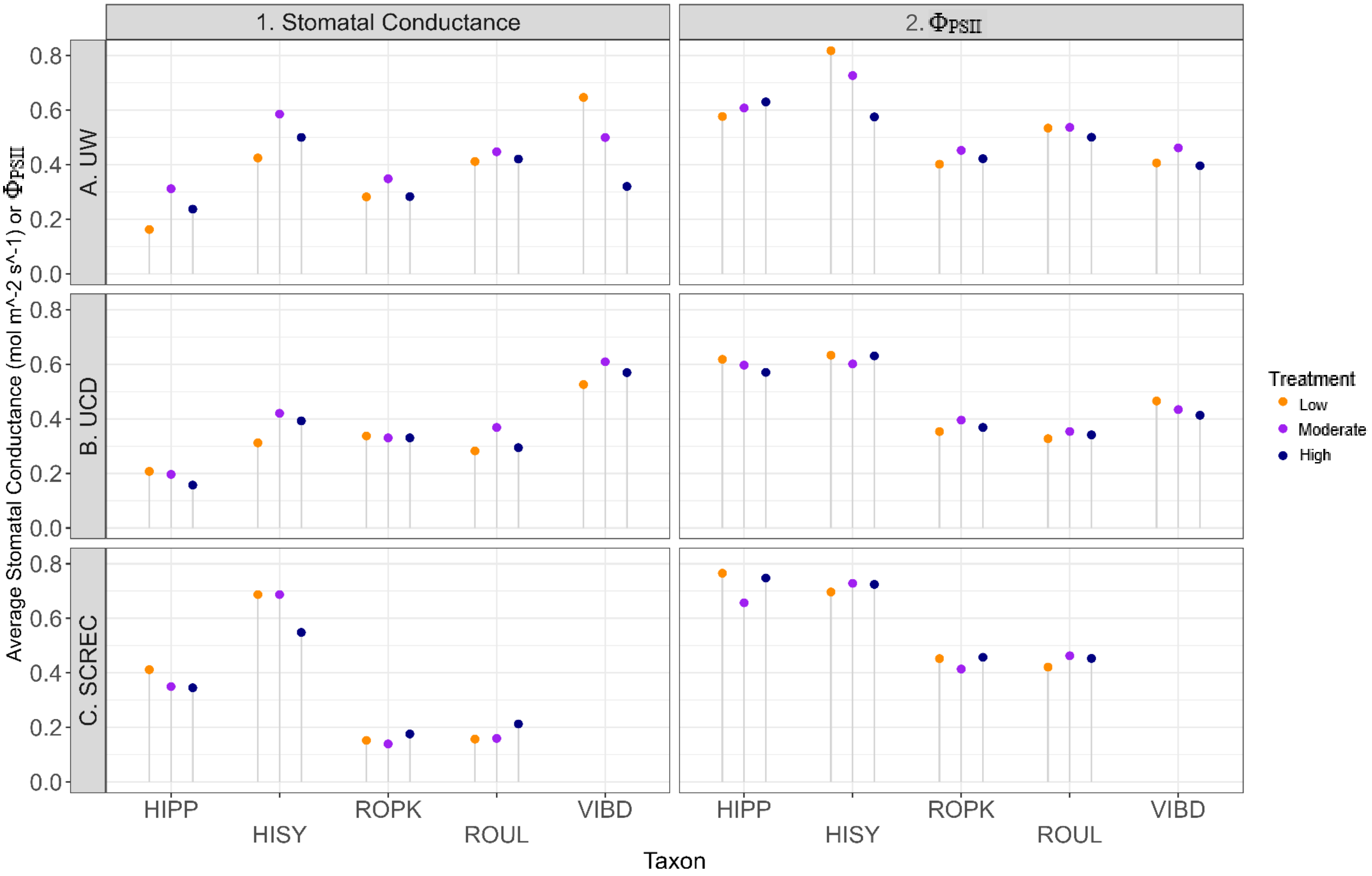

Fig. S2 Average stomatal conductance (mol m^{-2} s^{-1}) and Φ_{PSII} for each site and taxa combination A) UW, B) UCD, and C) SCREC. Treatment is indicated by the color of the dots. Taxa are broken down into their species code, HIPP is *Hibiscus syriacus* ‘Gandini Santiago’, HISY is *Hibiscus syriacus* 'ORSTHIB5x1', ROPK is *Rosa* ‘Meibenbino’, ROUL is *Rosa* ‘ChewPatout’, and VIBD is *Vitex* ‘SMVACBD’.

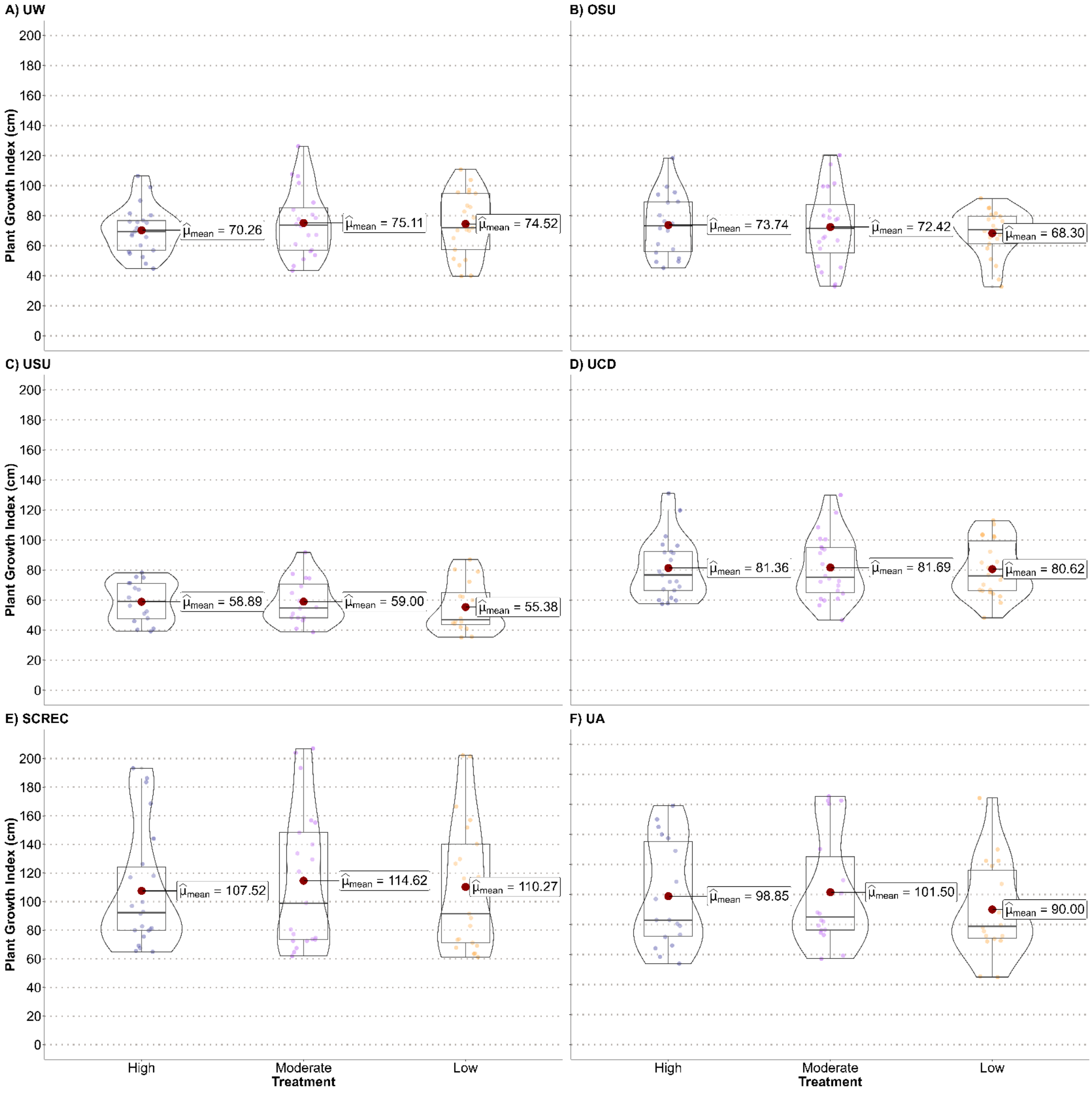

Fig. S3 Plant growth index (PGI, cm) distribution for each deficit treatment at each field site A) UW, B) OSU, C) USU, D) UCD, E) SCREC, and F) UA.