Growth and Flowering of *Salvia nemorosa* 'Ostfrieland' in Response to Reduced Irrigation[1]

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Abstract

Reduced irrigation (RI) can conserve water and control plant growth; however, the timing of RI applications can impact plant growth and flowering. The goal of this research was to quantify growth of *Salvia nemorosa* L. 'Ostfrieland' (East Friesland) in response to RI. A soil-moisture sensor automated irrigation system was used to apply four irrigation treatments: RI and well-watered (WW) controls (20% and 38% substrate water content) and two combination treatments to apply RI for either the first two weeks (20% followed by 38%, RIWW) or final four weeks (38% followed by 20%, WWRI) of the six-week study. Flower number, height, compactness, and relative chlorophyll content (SPAD) were not different across treatments. Average flower stem length was greater for the WW and RIWW treatments than for the RI treatment. Shoot dry weight was less for the RI treatment compared to the WW and RIWW treatments, respectively]. Cumulative irrigation volume was lowest for the RI treatment and highest for the RIWW treatment. Visually, plants in the RIWW treatment had an open, floppy habit that would likely negatively impact sales in a retail setting. Plants in the RI treatment were smaller, but visually appealing.

Index words: soil moisture sensor, plant production, herbaceous perennial, container plants.

Species used in this study: 'Ostfrieland' salvia (*Salvia nemorosa* L.).

Significance to the Horticulture Industry

Controlling plant growth is common in greenhouse and nursery production. Managing the size and flowering of plants is necessary to meet consumer preferences of what quality plant material should look like. More compact plants are also beneficial to both the grower and consumer as more plants can fit in a truck, reducing the shipping cost. Hand pruning and plant growth regulators are commonly used to control plant growth; however, hand pruning is labor intensive and plant growth regulators can vary in effectiveness. Reduced irrigation can be used as a means of growth control, but the degree and timing of the reduced irrigation need to be managed to avoid poor or uneven growth. This study examined the use of reduced irrigation and altering reduced irrigation with higher irrigation volume (well-watered) on growth and flowering of *Salvia nemorosa* 'Ostfrieland'. Reduced irrigation resulted in smaller plants with reduced flower stem length and reduced branching, but plants receiving this treatment were visually appealing. The implementation of reduced irrigation, followed by well-watered conditions resulted in a floppy growth habit that could impact salability. The results of this study show that timing of reduced irrigation applications need to be managed in order to produce plants with desirable growth. Reduced irrigation can be used to produce smaller, visually-appealing *Salvia nemorosa* 'Ostfrieland' without significantly reducing the number of flowers.

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Introduction

High volumes of water are commonly used in plant production (Fulcher et al. 2016). However, increasing demand on water resources due to climate change, drought events, and competition for water use has resulted in a growing need for greenhouse and nursery growers to better manage water resources (Cameron et al. 2004, Fulcher et al. 2016). Many commercial growers irrigate frequently and fertilize at a high level in order to maximize plant growth (Richards and Reed 2004). This can result in plants with disproportionate growth, long internodes, and reduced axillary growth (Cameron et al. 2008, Koniarski and Matysiak 2013).These practices can result in nutrient laden runoff which can enter into local ecosystems (Fulcher et al. 2016).

Hand pruning and plant growth regulators (PGRs) are currently used to control plant growth and to promote increased branching (Cochran et al. 2013). Hand pruning is time consuming and is labor intensive, leading to increased production costs (Holland et al. 2007). Plant growth regulators may be effective, but their efficacy may vary across ornamental plant species, environmental conditions, substrates, irrigation practices, and method of application (Cochran et al. 2013, Cole et al. 2013, Keever 2003, Kessler and Keever 2008). Potential restrictions on the use of PGRs in some countries (Clifford et al. 2004), and growing concerns about agrochemical use in plant production and their presence in runoff, are causing an increased interest in alternative means of plant growth control (Kaufmann et al. 2000). PGRs can also have negative effects on plant growth including smaller flowers (Cochran et al. 2013) and fewer leaves (Cole et al. 2013). Pruning can also have negative effects that include dieback after shearing (Cole et al. 2013).

Deficit irrigation can also be used as a means of growth control; however, many growers are reluctant to use this method due to the possibility of negatively impacting overall plant growth (Bailey and Whipker 1998). Applying deficit irrigation can be a challenge in a production setting because over- or under-irrigation is common due to poor uniformity or efficiency of the irrigation system. More precise irrigation applications with automated sensor-controlled irrigation can provide growers with a more reliable means of applying deficit irrigation (Alem et al. 2015). Precise application of deficit irrigation can improve plant quality with increased branching, reduced internode length, and enhanced flowering (Koniarski and Matysiak 2013). Reduced irrigation volume and more precise irrigation applications can save water, but can also benefit growers by reducing labor, energy costs, fertilizer and pesticide applications, and potentially shorten production time (Lichtenberg et al. 2013).

Plant quality control can be a large component of container plant production as uneven growth and poor branching may lead to customer rejection of such plants, resulting in reduced sales (Koniarski and Matysiak 2013). Consumers often purchase plants based on the perception that plant health and visual appearance correspond. Uniform growth, leaves on lower branches, dense foliage, leaf color, and bloom quality can all impact the visual appearance and appeal of a plant to a consumer (Brand and Leonard 2001, Glasgow et al. 1998). Poor uniformity of plants can result from uneven irrigation distribution, variation in pruning from person to person, or that application of PGRs needs to be varied based on species, substrate, and application timing. The production of more compact plants could also impact shipping costs. Container plants are often stacked or racked during shipping (Eaton et al. 2014), meaning smaller, more compact plants create the potential to fit more plants on a truck. Another benefit of deficit irrigation is the potential to help plants gain tolerance to drought stress conditions that may be encountered in a retail nursery or home landscape setting (Cameron et al. 2008).

The effectiveness of deficit irrigation on controlling plant growth has been reported for many varieties of ornamental plants. Sensor-controlled irrigation studies have shown reduced growth with lower volumetric water content thresholds for *Hibiscus acetosella* Welw. ex Hiern. 'Panama Red' (Bayer et al. 2013), *Gardenia jasminoides* Ellis 'Radicans' and 'August Beauty' (Bayer et al. 2015a), *Gaura lindheimeri* Engelm. & Gray 'Siskiyou Pink' (Burnett and van Iersel 2008), *Hydrangea macrophylla* Thunb. 'Mini Penny' (van Iersel et al. 2009), and *Lantana camara* L. (Bayer et al. 2014). The timing of deficit irrigation applications has been reported to impact flower bud development along with controlling plant growth. Results indicate that deficit irrigation during floral initiation can both promote flowering and can inhibit flowering depending on the species and degree of water stress (Cameron et al. 1999, Álvarez et al. 2009, Sharp et al. 2009, Álvarez et al. 2013, Koniarski and Matysiak 2013). More information is needed on the timing of deficit irrigation applications on the growth and flowering of flowering species in order to best utilize this method. The objectives of this research were to determine the impact of deficit irrigation application timing on growth, flowering, and plant quality of *Salvia nemorosa* 'Ostfriesland'.

Materials and Methods

Plants. Research was conducted in the College of Natural Sciences Research Greenhouses at the University of Massachusetts in Amherst, MA from 27 September, 2016 to 23 March, 2017. Rooted cuttings of *Salvia nemorosa* 'Ostfriesland' were obtained from Pioneer Gardens, Inc. (Deerfield, MA) on 27 September, 2016. Cuttings were planted in 2.8 L (0.74 gal) black plastic containers filled with a commercial substrate containing pine bark (75% by volume), peat (25% by volume), Dolomitic limestone, a wetting agent, and starter nutrients (Fafard RSI Nursery Mix, Sun-Gro, Agawam, MA). Plants were given an establishment period to allow for root growth, during this time plants were hand watered. After 2 months, plants were cut back to the substrate and containers were topdressed with 11 g (0.39 oz) of controlled release fertilizer (Nutricote Total 18-6-8, 180 d; 18.0 N- 2.6P- 6.6K, Florikan E.S.A LLC. Sarasota, FL). After cutting back and fertilization, plants were given 1 month to resume growth before initiating irrigation treatments on 10 February, 2017. For combination irrigation treatment volumetric water content setpoints were switched on 25 February, 2017 and the experiment was concluded on March 23rd.

Treatments and data collection. There were four substrate water content treatments: a well-watered control (38%; WW), a reduced irrigation control (25%; RI), altering water content from well-watered to reduced irrigation (38% to 25% $m^3 \cdot m^{-3}$; WWRI) after two weeks and altering water content from reduced irrigation to well-watered (25% to 38%; RIWW) after two weeks. Substrate water content setpoints were based on previous research to provide well-watered and moderate water stress conditions.

A soil moisture sensor-controlled irrigation system, based on that described by Nemali and van Iersel (2006), was used for irrigation. There were four irrigation lines per replication to apply the four irrigation treatments and three replications for a total of 12 irrigation lines. Soil moisture sensors (10HS, Decagon Devices, Pullman, WA) were inserted into two pots in each of the 12 irrigation lines at a 45° angle into the center of the substrate so that the entire sensor was in the substrate. The 24 sensors were connected to a multiplexer (AM16/32B, Campbell Scientific, Logan, UT) connected to a datalogger (CR1000, Campbell Scientific).

The datalogger measured sensor voltage output every 60 minutes. The voltage readings from the sensors were converted to volumetric water content (θ) using a substrate specific calibration [$\theta = -0.4207 + 0.0009 \times \text{output (V)}$] using the method described by Nemali et al. (2007). When both sensors in a line were below the line θ threshold (20% or 38%), the datalogger signaled the relay driver (SDM16AC/DC controller, Campbell Scientific) to open the appropriate solenoid valve (sprinkler valve, Rainbird, Azusa, CA). Plants were irrigated for 1 minute, applying 35 mL (1.18 oz) of water via drip tubing connected to pressure-compensated drip emitters (Netafim USA, Fresno, CA).

Readings from each sensor were averaged and recorded every 60 minutes, and number of irrigation events per line was recorded daily. Daily and total irrigation volume for a line was calculated from the number of irrigation events and the volume of water applied per irrigation event.

Height was measured biweekly. Flower number, length of stems and number of branched stems were measured at the conclusion of the experiment. Shoots were cut off at the substrate surface and were dried at 50 C (122 F) after which dry weight was determined. Compactness was calculated as shoot dry weight/plant height. SPAD values were measured using a chlorophyll meter (SPAD 502DL Plus, Minolta, Japan).

Experimental design and data analysis. The experiment was designed as a randomized complete block with four treatments (substrate water content set points) and three replications for a total of twelve plots with five pseudoreplicate plants each. Data was analyzed using the PROC GLM procedure of SAS (Version 9.4, SAS Institute, Cary, NC) with P = 0.05 considered statistically significant. Treatment means were separated using Tukey's honestly significant difference. Curve fitting was done using SigmaPlot (Systat, San Jose, CA).

Results and Discussion

Average number of flowers was not significant across treatments (Table 1). There was no difference across treatments in days to first flower (data now shown). Flower stem length of plants receiving the RI treatment [34.9 cm (13.7 in)] was 19% shorter than plants receiving the WW and RIWW treatments [43.0 cm (16.9 in) and 44.8 cm (17.6 in), respectively], which were similar to plants receiving the WWRI treatment [39.4 cm (15.5 in), Table 1]. Number of branched flower stems was 23% less for the RI treatment (5.7) than the RIWW treatment (8.5). Number of branched flower stems was similar for the RIWW (8.5), WW (7.4), and WWRI treatments (6.9).

The impact of reduced irrigation on flower development varies with species, timing, and degree of irrigation reduction or water stress. Similar to this study, there was no difference in number of flowers for *Lantana camara* L. 'New Gold', *Lobelia cardinalis* L., *Salvia farinacea* Benth.'Henry Duelberg', or *Scaevola aemula* R. Br. 'New Wonder' (Starman and Lombardini, 2006) maintained at container capacity or subjected to one or two drought cycles. Severe water stress (35% of the control) reduced the number of flowers per plants of *Dianthus caryophyllus* L., moderate water stress (70% of the control) did not (Álvarez et al. 2009). Other studies have found reduced irrigation treatments reduced number of flowers or flower size. Nui et al. (2017) found that *Lupinus havardii* Wats. irrigated at 20, 25, and 33% VWC had a similar number of cut racemes whereas plants irrigated at 12 and 15% VWC had 35% less racemes. Flower number of *Rosa hybrida* L. 'RADrazz' and 'Belinda's Dream' was not different for plants irrigated to maintain substrate moisture contents (SMC) of 30 or 40%; however, flower number was reduced by 27% and 86% for the 20% and 10% SMC treatments for 'Radrazz' and by 42% and 75% for the 20% and 10% SMC treatments for 'Belinda's Dream' (Cai et al. 2014). Alem et al. (2015) found that bract size of *Euphorbia pulcherrima* Willd. ex Klotzsch 'Classic Red' was reduced with increased duration of the water deficit application. Guo et al. (2018) found that there was no difference in flower stem length for *Angelonia angustifolia* L. 'Angelface Blue' or *Heliotropium arborescens* L. 'Simply Scentsational' but found a species-specific response to reduced irrigation in regards to number of flowers and buds. Similar to this study, *Angelonia angustifolia* 'Angelface Blue' flower and bud numbers did not differ for the 20% and 40% substrate moisture content treatments; conversely flower number was greater for the 20% SMC treatment compared to the 40% SMC treatment for *Heliotropium arborescens* 'Simply Scentsational' (Guo et al. 2018).

Table 1. Flower measurements or 'Ostfrieland' salvia (*Salvia nemorosa* L.) at the conclusion of the 42-day experiment as affected by irrigation treatment. (n=3). [z]

Treatment[y]	Flower number	Average flower stem length (cm)	Branched flower stems
Well- watered	8.7	43.0a	7.4ab
Reduced irrigation fb well-watered	9.1	44.8a	8.5a
Well- watered fb reduced irrigation	8.1	39.4ab	6.9ab
Reduced irrigation	7.4	34.9b	5.7b
P-value	0.06	0.02	0.04

[z]Means within a column with different letters are different ($\alpha = 0.05$) according to the Tukey's honestly significant difference tests. Each value is the mean of three replications with each replication consisting of five pseudoreplicate plants.

[y]Treatments were irrigated for 42 days, or watered for 2 weeks followed by (fb) a different schedule.

Koniarski and Matysiak (2013) found *Rhododendron* L. 'Catawbiense Boursault' grown with RI treatments during the flower bud development stage had a higher number of inflorescence buds compared to the well-watered control and that *Rhododendron* 'Old Port' had a greater number of inflorescence buds when very strong deficit irrigation (25% of evapotranspiration) was applied during the floral bud development phase compared to the well-watered control. Álvarez et al. (2013) found that *Pelargonium* x *hortorum* L.H. Bailey flowering was lowest when deficit irrigation was applied during flowering. The results of these studies show that reduced irrigation effect on flower number and flower size varies based on plant species, level of irrigation reduction, and timing of reduced irrigation application.

Irrigation treatment did not affect salvia height (Table 2). In contrast, other studies found that there was generally a reduction in height with reduced or deficit irrigation. Height of *Dianthus caryophyllus* decreased with increasing level of deficit irrigation (Álvarez et al. 2009). Height of *Euphorbia pulcherrima* 'Classic Red' was successfully reduced by using controlled deficit irrigation applications (Alem et al., 2015).

Table 2. **Growth measurements and cumulative irrigation volume for 'Ostfrieland' salvia (*Salvia nemorosa* L.) at the conclusion of the 42-day experiment as affected by irrigation treatment. Compactness was calculated as shoot dry weight/shoot length (n=3).** [z]

	Height (cm)	Shoot dry Weight (g)	Compactness ($g.m^{-1}$)	SPAD	Cumulative irrigation volume (L/plant)
Well- watered	48.9	22.4a	0.05	45.1	3.2ab
Reduced irrigation fb well-watered	49.0	23.8a	0.046	46.3	3.6a
Well- watered fb reduced irrigation	45.1	17.8ab	0.039	47.5	2.6ab
Reduced irrigation	40.0	14.4b	0.035	48.9	2.3b
P-value	0.06	0.01	0.06	0.22	0.03

[z]Means within a column with different letters are different ($\alpha = 0.05$) according to the Tukey's honestly significant difference tests. Each value is the mean of three replications with each replication consisting of five pseudoreplicate plants.

[y]Treatments were irrigated for 42 days, or watered for 2 weeks followed by (fb) a different schedule.

Application of deficit irrigation at different phases of production (vegetative or flowering) produced varied results. Álvarez et al. (2013) found that *Pelargonium* x *hortorum* height was lowest when deficit irrigation was applied during the flowering phase and plant height remained inhibited for a few weeks after the deficit irrigation application. Koniarski and Matysiak (2013) found that plant height of 'Old Port' rhododendron irrigated moderate deficit irrigation (75% of evapotranspiration), severe deficit irrigation (50% of evapotranspiration), and severe deficit irrigation during the vegetative growth stage (50% of evapotranspiration) was lower compared to the control by 12%, 25%, and 21% respectively. 'Catawbiense Boursault' rhododendron had reduced height for the moderate deficit irrigation (50% of evapotranspiration) and moderate deficit irrigation during vegetative growth stage treatments compared to the well-watered control. Reduced irrigation during the floral bud development stage resulted in reduced height of 'Old Port' by 8% and 13% for the 50% and 25% reduction treatments. There was a rapid increase in growth of Saliva in the RIWW treatment after the irrigation setpoint was switched, which could have contributed to the floppy habit of the RIWW plants at the conclusion of the experiment. The sudden increase in irrigation frequency may have contributed to the irregular growth observed for plants in the RIWW treatment.

Shoot dry weight was least for the RI treatment and similar for the WW, RIWW, and WWRI treatments (Table 2). Shoot dry weight for the RIWW treatment was 6% higher [23.8 g (0.84 oz)] than the WW control, while shoot dry weight in the WWRI and RI treatments were 20% [17.8 g (0.63 oz) and 36% 14.4 g (0.51 oz)] less than the WW control [22.4 g (0.79 oz)], respectively. Shoot dry weight of *Lupinus harardii* generally decreased with decreasing VWC. Álvarez et al. (2009) found that shoot dry weight of *Dianthus caryophyllus* decreased with decreasing irrigation level. Cai et al. (2014) found that shoot dry weight was reduced by 25% and 86% for the 10% and 20% SMC treatments for *Rosa hybrida* 'RADrazz' and by 30% and 87% for 'Belinda's Dream'. Guo et al. (2018) found that shoot dry weight of *Angelonia angustifolia* 'Angelface Blue' was reduced for plants grown at 20% SMC, but that shoot dry weight of *Heliotropium arborescens* 'Simply Scentsational' was similar for plants grown at 20% and 40% SMC. Álvarez et al. (2013) found that shoot dry weight of *Pelargonium x hortorum* decreased with deficit irrigation during any growth phase. The results of this study was similar to others in that the RI treatment resulted in reduced shoot dry weight. However, unlike the Álvarez et al. (2013) results, applying reduced irrigation during only part of the experiment did not result in significantly reduced shoot dry weight (Table 2).

Plant compactness, measured as shoot dry weight/plant height was not significantly different across irrigation treatments (Table 2). These results are similar to those of van Iersel et al. (2004), which found that drought stress results in shorter but not more compact *Tagetes erecta* L. and Bayer et al. (2015b) which found that irrigation volume had no effect on compactness of *Gardenia jasminoides* 'MADGA I'.

Leaf SPAD readings were not different for any treatments (Table 2), indicating no impact on relative chlorophyll content per leaf area. Koniarski and Matysiak (2013) also reported no difference in relative chlorophyll content index for either Rhododendron 'Catawbiense Boursault' or 'Old Port'. Nui et al. (2017) found that *Lupinus havardii* leaf SPAD readings were less for the 12 and 15% VWC treatments.

Cumulative irrigation volume was greater for the RIWW treatment than the WW control (17% greater, Table 2). These results suggest that applying reduced irrigation early in the production period may result in increased water usage later if plants are provided increased irrigation volume. Switching from well-watered to reduced irrigation later in production helped to conserve water use. Koniarski and Matysiak (2013) found that irrigation volume decreased with level of deficit irrigation and that significant deficit irrigation at any point in the experiment resulted in reduced irrigation volume compared to the well-watered control. Moderate deficit irrigation resulted in similar irrigation volume to the control regardless if it was applied during the entire experiment or during either the vegetative or floral bud development stages. Total irrigation amount was similar for all deficit irrigation treatments applied to *Pelargonium* x *hortorum* (Álvarez et al. 2013). Results of this study are similar to others that the RI treatment resulted in the lowest irrigation volume but differ in that the RIWW treatment had the highest irrigation volume. This difference in the RIWW treatment to others that used reduced irrigation during part of an experiment may be due to the length of the reduced irrigation period or differences in the plant species' physiology or ability to deal with water stress.

The reduced irrigation treatment resulted in smaller plants with shorter, less branched flower stems. The RI plants were more visually appealing, appearing more compact and proportional than other treatments. Reduced irrigation followed by well-watered conditions resulted in rapid growth and an uneven, floppy habit. Irregular growth can be common with excessive irrigation due to long internodes and disproportionate apical growth (Koniarski and Matysiak 2013). The RIWW plants were not visually appealing due to the floppy habit, which could reduce the salability of the plants. These results are both similar and in contrast to others. Koniarski and Matysiak (2013) which found that reduced irrigation treatments had better visual quality than the well-watered plants. The well-watered plants were reported to have long internodes and an uneven appearance, which is similar to the plants receiving the RIWW treatment in this experiment. Álvarez et al. (2013) found that plant quality and flowering did not only depend on the amount of water applied but also on the time when the reduction was applied. Nui et al. (2017) also postulated that timing of water stress imposition can influence growth and flower development.

The results of this study further demonstrate that plant growth and flowering are impacted by the timing and degree of RI. The increased growth of the RIWW treatment may indicate that plant species that grow rapidly, such as salvia, may be more likely to have undesirable growth when switched from reduced irrigation to well-watered conditions. This could potentially impact these plants as they move from a production setting to a retail setting where irrigation volume could change and over-irrigation is common. Reduced irrigation at any point in the experiment resulted in a reduction in cumulative irrigation volume compared to the WW treatment.

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