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Research Article

Effects of Deficit Irrigation in Pepper Plants (*Capsicum annuum*) Grown Under Greenhouse Conditions

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Abstract

Water is a vital component for agricultural productivity; however, freshwater supplies are limited and are dwindling worldwide. Water for agriculture is an extreme issue for the southern region of Texas, where water supplies from reservoirs are used for municipal, industrial, and agricultural purposes. Due to intensive and prolonged intermittent droughts in south Texas, freshwater sources can deplete rapidly leaving growers on water restrictions. One potential solution of reducing the amount of water for crops is by applying less water than recommended crop evapotranspiration requires. Deficit irrigation (DI) is the practice of applying lower amounts of water than general crop requirements to increase water use efficiency for economic benefit. Deficit irrigation practice has been shown to be beneficial to some fruit and vegetable crops, but to a lesser extent in south Texas for mild heat pepper plant production. The purpose of this project was to analyze how watering jalapeño and serrano pepper plants at different levels of DI would impact plant growth and fruit yield in a greenhouse study. Deficit irrigation treatments were performed by irrigating pots at increasing the number of days between irrigation events (water application: 2, 4, 8, and 12 days) to create increasing water stress levels to plants. Plant growth and biomass data was collected to determine the impact of increasing deficit irrigation on plant shoot productivity. In both varieties, plant biomass steadily decreased as water application decreased. Serrano peppers grown at both 4d and 2d between water application events produced identical yields, however, increased water stress immediately impacted jalapeño peppers with lower yield. The encouraging results from serrano peppers suggest a potential economic benefit for deficit irrigation water use practices applied to this pepper variety.

Keywords: Deficit irrigation; Water conservation; Plant stress; Water use efficiency

Introduction

South Texas faces major water challenges that make its conservation difficult. In the last twenty years, the Rio Grande, the fifth largest river in North America, has begun to dry up and an extremely low level of water flow has been recorded. This has been caused by an over-allocation of water by agricultural development, and no structure for sustainable use. Besides this, the United States and Mexico share the water of the Rio Grande, and Mexico has had difficulties maintaining its end of a treaty established in 1944. Prolonged and severe periods of drought have jeopardized agricultural production on either side of the border and are expected to continue in the future [1]. Jalapeño and serrano peppers are grown in south Texas, and with a moderate irrigation requirement compared to other horticultural crops, they are still directly affected negatively by drought or lack of water [2,3]. Peppers are a common crop grown for their edible fruit which can be utilized whole or processed into salsas, sauces, or seasoning. Hot peppers generally have a low market value, as they are often produced in abundance. However, as all southern grown crops are being faced with severe drought, prices have increased. Furthermore, the high demand for mild, low heat peppers in the American diet and globally has significantly increased the importance of peppers crops. As low heat peppers, like jalapeño, poblano and Anaheim, continue to increase in diet adoption in the U.S., these peppers have moved from an ethnic specialty to mainstream food consumption product [4]. These crops are commonly produced in arid and semi-arid regions; the need for water conserving practices to produce more peppers in regions of limiting freshwater supplies is essential worldwide. Deficit irrigation in greenhouse grown peppers is becoming of high interest [2,5].

Materials and Methods

This study was conducted in a Dick and Mary Lewis Kleberg College of Agriculture and Natural Resources greenhouse at Texas A&M University– Kingsville, located at coordinates 27° 31' 50.3" N, 97° 53' 13.8" W. Temperatures in the greenhouse throughout the duration of the experiment averaged 30°C. Capsicum annum varieties were planted from seed using Ferry Morse® heirloom jalapeño and serrano varieties (Detroit, MI). Seeds were allowed to grow for three weeks and seedlings were then transplanted into 25.4-cm dia., 3.8 L (10-inch dia., one gallon) pots. Seedlings were allowed to grow for another 3 weeks prior to the initiation of water stress treatments. Pepper plants were sorted according to similar plant height and canopy width, where 16 plants were selected per pepper variety. Pots for each pepper variety were arranged on the greenhouse table in a randomized complete block design for later statistical data analysis. Each water deficit irrigation (DI) treatment was replicated four times among four blocks. Water stress or deficit irrigation treatments were based on watering day intervals (days between watering). The four-water application (or deficit irrigation, DI) treatments were 2, 4, 8, and 12d between irrigation events; where 2d and 12d treatments as the lowest and highest water stress, respectively. The lowest water stress treatment was irrigated every two days (2d), whereas the other DI treatments (4d, 8d, and 12d) were irrigated every four, eight, and twelve days, respectively [6]. When plants were being irrigated on their appropriate treatment interval days, the pots were watered to full saturation and permitted to fully drain to field capacity.

All plants were fertilized at 11.2 Kg N/ha (10 lbs N/acre) with 24:8:16 NPK fertilizer twice in the duration of this experiment. Data was collected weekly including plant shoot height and canopy leaf width, and as fruit ripened, we assessed fruit parameters: fruit yield, length, width, weight, and number of seeds per fruit. Treatments were terminated after 83 growing days and at the conclusion of the experiment, plant leaves and shoots were cut and placed into paper bags. Plant shoot fresh weight data was recorded, then bags were placed in a 65 ºC drying room until all leaves and shoots were air dry. The shoot dry weight was determined for all treatments and replications for both pepper varieties.

Results and Discussion

Average plant height was 15 cm (±2 cm) at the start of the varying irrigation treatments (Figure 1). All pots were irrigated to saturation and allowed to drain to field capacity to initiate (time = day 0) the irrigation treatments. Pepper plant growth and development were measured for height and canopy width over 83 days during the evaluation of the water stress treatments. Pepper plant height was found to be a more meaningful indicator of irrigation treatment effects on plant growth so results presented emphasize plant height. Pepper plant shoot growth and vigor within greenhouse growing conditions were impacted by increasing water deficit stress level, as evidenced in photos of selected plants 70 days from the start of water use treatments (Figure 2). Plant height and growth over time decreased as water stress level increased for both Jalapeño and Serrano peppers. There was notable difference among pepper varieties, as increasing water stress over time led to progressive decline in jalapeño pepper plant height and vigor among water treatments (Figure 1), whereas serrano pepper plant height in nearly all treatments paralleled that of the lowest water stress irrigation treatment (2d watering). Statistical analysis of variance (ANOVA) and t-test comparison of means was performed on ultimate plant height among treatments for each pepper variety (Table 1). Statistical differences were observed among plant height among water application treatments in jalapeño pepper as ANOVA (p-value = 0.0036). Means comparison t-tests showed no statistical differences at the 95% confidence level among 2d and 4d (p-value = 0.0550) watering treatments (p-value > 0.05), however, 8d and 12d watering treatments were statistically different than that of 2d water applied treatment (p-values = 0.0002 and 0.0238, respectively). Furthermore, statistical differences in plant height were observed between 4d and 8d watering treatments (p-value = 0.0195). These results suggest that plant productivity for jalapeño pepper is negatively affected by progressively higher water stress or drought. In contrast, there were no statistical difference in plant height among the varying watering application treatments in serrano pepper for both ANOVA (p value = 0.6070) and t-test means comparisons (all p-values > 0.05), signifying that serrano pepper is more tolerant to drought and high-water stress than that of jalapeño pepper.

Table 1: Comparative t-test analysis of means for final plant height among water application treatments (Trts). P-values < 0.05 level represents plant growth was significantly different among water stress treatments (2d, 4d, 8d, 12d between watering), and six degrees of freedom between treatment comparisons. ANOVA results for Jalapeño pepper: p-value = 0.0036; Serrano pepper: p-value = 0.6070.

Trts-Jalapeño	Mean Diff	p-value	Trts-Serrano	Mean Diff	p-value
2d Vs 4d	3.165	0.055	**2d Vs 4d**	4.282	0.2316
2d Vs 8d	7.155	0.0002	**2d Vs 8d**	1.865	0.6023
2d Vs 12d	4.707	0.0238	**2d Vs 12d**	3.595	0.3848

4d Vs 8d	3.99	0.0195	**4d Vs 8d**	2.418	0.3526
4d Vs 12d	1.543	0.4228	**4d Vs 12d**	0.688	0.826
8d Vs 12d	2.448	0.1554	**8d Vs 12d**	1.73	0.6061

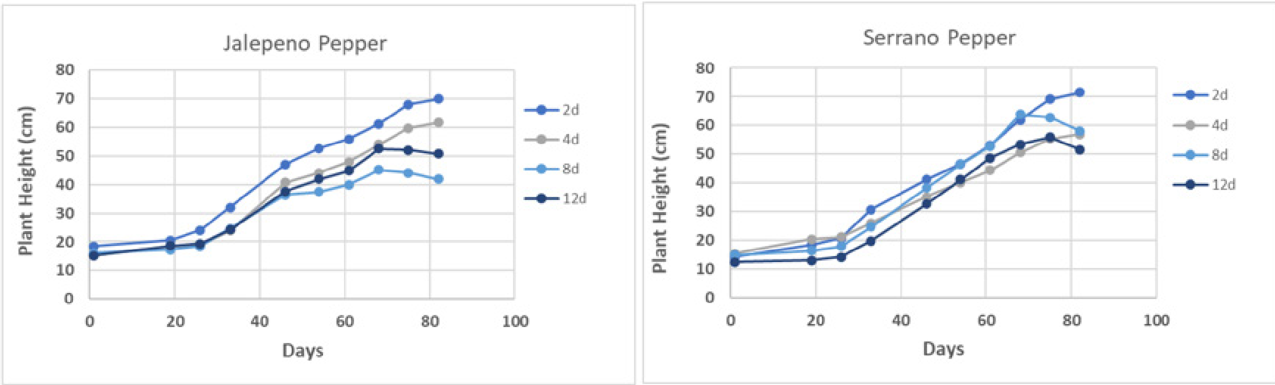

Figure 1: Average plant height of Jalapeño and Serrano pepper plants grown in the greenhouse from the initial start date (time = 0 days) for varying water stress treatments (2d, 4d, 8d, and 12d) through the end of the study (83 days).

Figure 2: Jalapeño pepper (Left photo) and Serrano pepper (Right photo) plant vigor near end of study with increasing water deficit levels (2d, 4d, 8d, 12d between irrigating pots to saturation) from Left to Right.

The rate at which a plant is increasing or decreasing in growth can be measured by relative growth rate (RGR) [7,8], and in this assessment we monitored RGR for plant height in cm growth per day (cm d^{-1}) as shown in Figure 3 for both pepper varieties. Growth rate was non-linear and best expressed using a 2nd-order polynomial equation (Figure 3), as evidenced by RGR overall increasing as plant shoot and leaf canopy expanded, followed by decreasing RGR as fruit production phase occurred and plant senescence occurred. As would be expected as water becomes more limited, with increasing water stress (time between irrigation events), the more rapid the decrease in RGR among treatments was observed. Of particular note, RGR stopped completely for several of the 12d and 8d water application treatments for both jalapeño and serrano peppers as evidenced by zero RGR between the final 70-82 days of the study (Figure 3). The higher and positive RGR values towards the end of the study days in the 2d and 4d watering treatments led to curves that were elevated in comparison to the 8d and 12d treatments. These higher 2nd-order curves for 2d and 4d treatments suggest that these plants have the likelihood for crop fruit production over the entire 83 day growing period and more sustainable for a longer period of time.

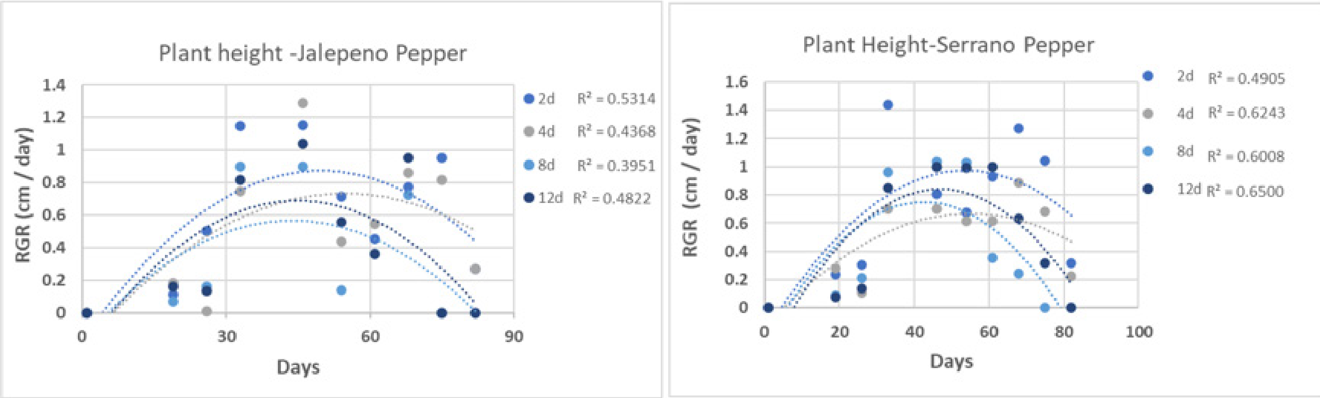

Figure 3: Jalapeño and serrano pepper daily relative growth rate (RGR) data distribution for water use application treatments over the length of study was non-linear and best fit 2nd order polynomial growth curves. R^2 values for data fit shown next to water deficit treatments (2d, 4d, 8d, and 12d between rewatering) ranged from 0.39 to 0.65.

The physiological growth differences among the different pepper varieties in response to drought stress is worth examining more closely. Jalapeño plants exhibited two separate peak periods in growth among all irrigation treatments (Figure 4), whereas such peaks were observed only in the 2d and 4d watering treatments for serrano pepper. These first peaks in RGR correlate to plant growth and expansion within the first 50 days followed by decline by either limited nutrient supply in the rooting zone, or a conservation of energy strategy as the plant starts to invest resources into fruit production. The second split application of fertilizer was applied midway in the study at 40 days and the second plant peak may be a response by pepper plants obtaining and utilizing that fertilizer towards renewed plant growth and fruit production. Pepper growth and yield response to macronutrients is essential for increasing pepper crop productivity [9,10] and may be the dominant role influencing this observed bimodal growth behavior. Serrano peppers in the varying water stress treatments exhibited growth habits much more constant over time as noted by more of a plateau or level RGR values between 30 to 60 days for the 4d, 8d and 12d watering treatments (Figure 4). The more even growth rate over time for serrano peppers may be further evidence of their ability to tolerate drought and potentially produce fruit more consistently under increasing water stress. Physiological differences at different growing stages among other crops in response to drought have been observed in horticultural and agronomic crop cultivars of pea, wheat, and rice [11,12].

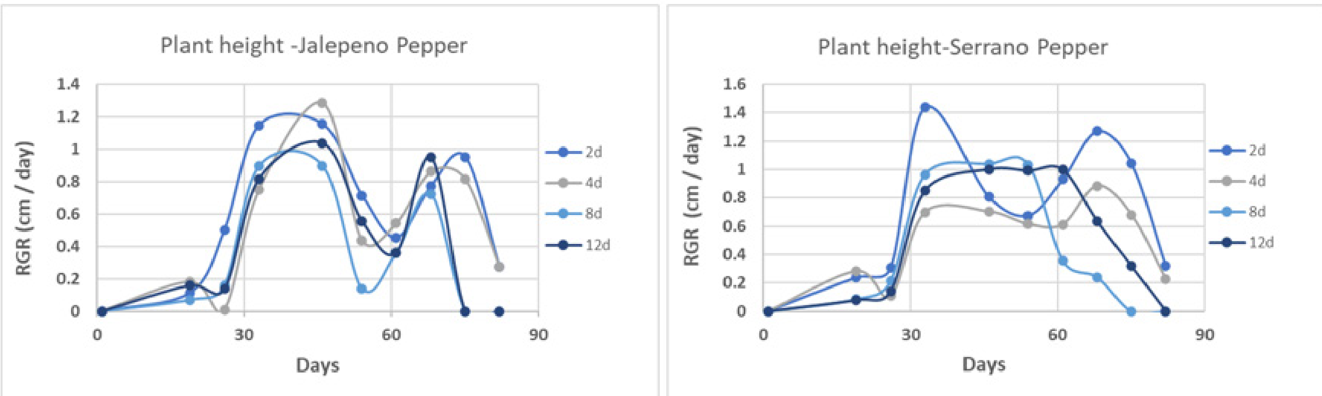

Figure 4: Plant height daily average relative growth rate (RGR) of jalapeño and serrano pepper plants over the water stress treatments (2d, 4d, 8d, and 12d between rewatering).

Plants were grown sufficiently long within the greenhouse to ensure fruit production was achieved and fruit was harvested periodically through the final 30 days of the growing season. Pepper fruit was harvested at fresh marketable size. Irrigation treatments and water use amount had no statistical difference on fruit size (fruit length, width, and seed content) in either plant variety. The impact of increasing water stress on jalapeño plants resulted in a sharp decrease in yield from 2d to 4d watering treatments, which nearly led to no fruit production in the 8d watering treatment (Figure 5), further indicating these plants may not have strong drought resistant qualities. This suggests that jalapeño may not be well adapted for DI as water deficit watering impacts yield too greatly for there to be an economic benefit to the greenhouse producer. In contrast, however, serrano pepper plants at both the 2d and 4d watering treatments produced identical total yield (Figure 5), and with more sustained fruit production for the 8d and 12d watering events, suggesting that there may be an economic benefit to deficit irrigation for this variety. The high fruit numbers observed in the 12d treatment is most likely a function of the plant expending as much energy as possible to produce seed due to the high extreme water stress conditions. Ge, et al. [13] observed similar findings with different maize varieties under drought stress, where water consumption is largely determined by the water deficit level, but overall water use efficiency is highly determined by genotype. Thus, variations in pepper plant genotypes at the variety level may lead to economic yield differences at the same water stress levels. For producers, the ratio of economic yield to water use consumption (water use efficiency, WUE) is the most vital information for a producer considering deficit irrigation [14,15]. In our greenhouse trial, there was nearly a 44% yield loss in watering jalapeño plants at 4d between watering events. This level of pepper fruit loss would not equal an economic benefit regardless of water savings. However, there is evidence of high potential economic benefit to watering serrano pepper plants at the 4d water stress treatment as the fruit yield was identical to that of the 2d watering treatment.

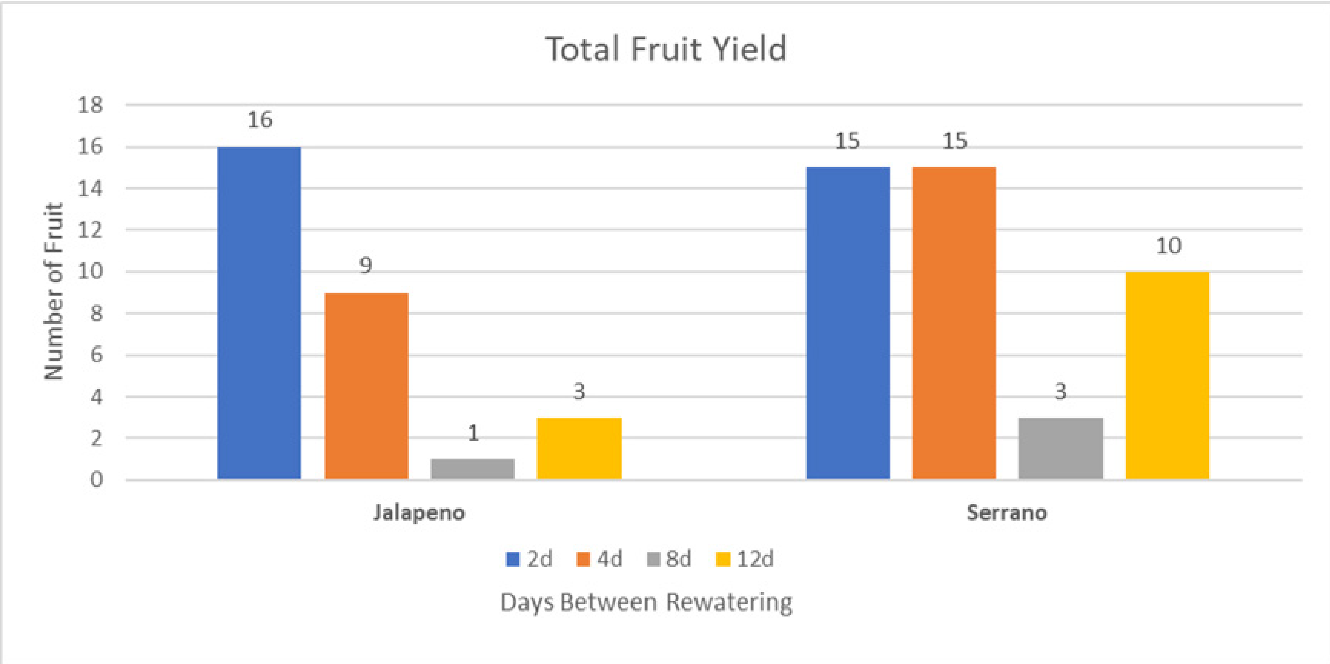

Figure 5: Pepper fruit yield (number of fruit) for jalapeño and serrano peppers for varying water stress application treatments (days between rewatering pots to saturation).

At the end of the greenhouse study, all plants were cut at the base of the shoot and plants were dried to assess total shoot biomass comparisons among treatments. The plant shoot and leaf biomass dry weight for both pepper plant varieties indicated a correlation of decreased total shoot biomass production with increasing water stress (Figure 6). It is noteworthy to mention that both jalapeño and serrano pepper biomass values decreased progressively from 2d through to 12d watering treatments, demonstrating that not only is plant height impacted, but plant canopy and leave production were affected progressively over time as visually demonstrated in Figure 2. Furthermore, final plant biomass does not include leaves lost by plants during the growing season, and especially during the final 30 days of the study where plants are trying to produce fruit in response to their respective water stress treatments. Despite decreasing biomass reduction over time with decreasing water application level, the 4d water stress treatment for serrano peppers is highly promising as the improved water savings in concert with high yield equivalent to that of 2d watering treatments suggests effective crop WUE. Abdelkhalik, et al. [5] recently observed similar findings where pepper plant yield and WUE were advantageous at water deficit irrigation (DI) of 75% but increasing water stress to 50% DI significantly impacted pepper fruit yield and led to blossom end rot of fruit. The serrano plants in this study show the most potential for success in relation to DI and it is recommended that future studies focus on this variety for water savings related greenhouse and field trials [16].

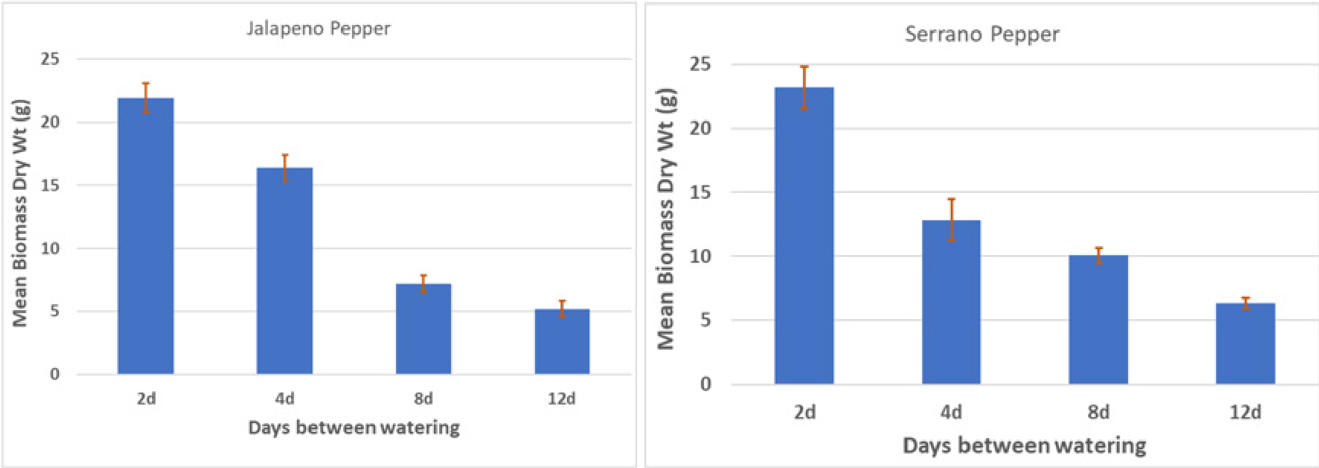

Figure 6: Jalapeño pepper and serrano pepper mean plant shoot biomass dry weight (Wt) for the varying water stress treatments (2d, 4d, 8d and 12d) at the end of the water deficit greenhouse study. Error bars in orange represent ±1 standard error of the mean.

Conclusion

This greenhouse study provides supportive evidence that mild pepper varieties respond differently to limited watering or deficit irrigation. Although plant biomass is negatively impacted by lower watering amount (higher water stress), pepper fruit yield can vary substantially dependent upon the variety and its ability to handle that stress into fruit production. Decreasing watering frequency from every other day to every four days did not lower serrano pepper yield, whereas it dramatically declined with jalapeño peppers. Serrano pepper plants demonstrated strong tendencies to handle high drought stress as fruit production numbers were high at the highest water stress level where plants were watered every 12 days. These encouraging fruit yield results from serrano peppers suggest that there may be a potential economic benefit to deficit irrigation for the serrano pepper variety. Results from this experiment will require additional studies to enhance our understanding of the water deficit limitations for serrano pepper production in greenhouse environments. As water and land supplies decrease worldwide, the need for sustainable alternatives to traditional irrigation and farming has increased the importance of studies like these in the horticultural industry.

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Conflict of Interest

No conflict of interest.

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