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Exploring the Legacy Practice of Flushing in Controlled-environment Production of High-CBD Cannabis (*Cannabis sativa*)

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Keywords. cannabinoid, cannabis, controlled environment, fertilizer restriction, greenhouse production, growth, inflorescence, plant nutrition, yield

Abstract. **In controlled-environment cannabis (*Cannabis sativa* L.) production, restricting fertilizer application and maintaining low substrate electrical conductivity (EC) before harvest, which is termed "flushing," is a standard procedure that is hypothesized to reduce inflorescence mineral nutrient concentrations, thereby improving dried inflorescence smoking quality, without impacting inflorescence yield. The objective of this study was to determine if flushing impacts yield, concentration of cannabinoids, or mineral nutrient concentrations of inflorescences. Two high-cannabidiol (CBD) cannabis cultivars, THM Jack and Southern OG, were flowered under a 12-hour photoperiod harvested at 7 weeks or 8 weeks, respectively. 'THM Jack' was subjected to preharvest flush durations from 0 to 3 weeks, and 'Southern OG' was subjected to preharvest flush durations from 0 to 4 weeks. Inflorescence dry mass ($kg \cdot m^{-2}$) declined as flush duration increased, but trim dry mass was unaffected. Additionally, Cannabidiol (CBD) and tetrahydrocannabinol (THC) concentrations were not impacted in 'THM Jack', but CBD concentration increased with flush duration in 'Southern OG'. The increase in CBD concentration did not compensate for the decline in inflorescence mass, which resulted in a decline in CBD yield ($g \cdot m^{-2}$). Nitrogen, phosphorus, and potassium concentrations declined in both cultivars as flush duration increased. Collectively, these results indicate that flushing can impact dry mass and tissue concentrations of cannabinoids and mineral nutrients. Whether these changes are beneficial depends on weighing a desired outcome (e.g., reduce fertilizer costs, improve smoking quality, manipulate cannabinoid concentration) against a loss in inflorescence and/or cannabinoid yield. Future research should evaluate how restriction of specific nutrients might impact inflorescence growth or organoleptic properties as well as potential differences in cultivar sensitivity to flushing based on seasonal variation in controlled environments.**

Preharvest nutrient restriction, termed "flushing," is a standard practice in controlled-environment cannabis production. Flushing generally involves terminating fertilizer application followed by leaching nutrients from the growing substrate and irrigating with clear water during the final 1 to 3 weeks before harvest. The prevailing justification is that flushing reduces inorganic mineral concentrations in inflorescence tissue, thereby improving smoking quality (Justice and Roggen 2021); a tangential benefit of flushing is that fertilizer cost is reduced. No study to date has demonstrated that flushing improves inflorescence smoking quality; therefore, the evidence supporting flushing for this purpose is anecdotal. An implicit assumption that flushing does not impact inflorescence yield is often overlooked ($kg \cdot m^{-2}$). The tradeoff between quality and yield is well-documented for other crops such as alfalfa (*Medicago sativa*) (Putnam et al. 2005) and strawberry (*Fragaria ×ananassa*) (Li et al. 2025); therefore, achieving both assumed outcomes with flushing is questionable. Unlike smoking quality, yield is quantifiable and thus the impact of flushing on cannabis flowering physiology has garnered substantial interest in recent years.

The earliest flushing studies were conducted by Stemeroff (2017) and Wedryk (2019), and both researchers indicated that flushing does little more than reduce fertilizer input during cannabis production. For example, Stemeroff (2017) found that flushing $\leq$ 2 weeks before harvest did not affect elemental nutrient or cannabinoid concentrations in dried inflorescences, nor did it affect inflorescence yield. Wedryk (2019) similarly reported no differences in inflorescence yield or tissue concentrations and further added that terpene concentrations were also unaffected. The flushing protocols in these studies were not well-described, and the lack of differences among flushing treatments might derive from failing to leach nutrients stored in the growing substrate, which means that the treated plants were not actually deprived of nutrients to a degree that could impact growth or secondary metabolism. Recent flushing research includes protocols that irrigate the growing substrate with clear water until leachate electrical conductivity (EC) measures $\leq$ 0.5 $mS \cdot cm^{-1}$ on the first day when flushing treatments begin and fertilization is terminated (Hershkowitz 2024; Saloner et al. 2024). Flush duration corresponds to the period before harvest when fertilizer is restricted and low substrate EC is maintained, which usually ranges from 1 to 3 weeks. Hershkowitz (2024) reported that inflorescence yield declined as flush duration increased, while Saloner et al. (2024) reported that a 2-week flush duration did not affect inflorescence yield. The results reported by Saloner et al. (2024) support earlier findings by Stemeroff (2017) and Wedryk (2019), while the findings reported by Hershkowitz (2024) indicate that flushing may be detrimental with respect to yield.

Controlled-environment crop production enables growers to precisely control inputs; therefore, minimum fertilizer thresholds can be identified. The temporal effects of nutrient availability on yield have substantial practical value for the cannabis industry, which is often criticized for excessive fertilization practices (Zheng et al. 2021). A recent industry survey reported that half of cannabis growers spend between 10% and 29% of their annual production budget on fertilizer (MacIver 2021), which is unusually high relative to the floriculture greenhouse industry, for which fertilizer accounts for $<$ 2% of the annual production budget (Hall 2022). High fertilizer costs are partly attributable to the use of cannabis-specific fertilizers, often as premade concentrated stock solutions, which are more expensive than conventional horticultural fertilizers that blend several inorganic fertilizer salts in granular form. Furthermore, supraoptimal fertilization rates are common, especially relating to phosphorus applications that often exceed 100 $mg \cdot L^{-1}$ during flowering (MacIver 2021; Westmoreland and Bugbee 2022). The combination of high-cost fertilizers and excessive fertilization results in a substantial input cost that causes growers to view flushing as a cost mitigation tool that improves inflorescence quality and may overlook potential consequences to inflorescence yield.

Our first objective was to determine whether increasing flush duration, defined as the period before harvest when low substrate EC is maintained, could impact dry mass yield, tissue concentration of cannabinoids, and mineral nutrient concentration. If flushing impacted these parameters, then our second objective was to understand how the changes in dry mass and tissue concentrations affected cannabinoid yield because this metric is critical for recreational and medicinal markets

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that offer extractable products (e.g., tinctures, waxes, oils) (Davenport 2021). We hypothesized that an inverse relationship between flush duration and dry mass would occur because nutrient limitation typically reduces yield (Fischer and Evans 1999); however, we suspected that a reduction in dry mass might accompany an increase in tissue concentration of cannabinoids or nutrients caused by yield dilution (Fan et al. 2008; Wang et al. 2018). Furthermore, we hypothesized that flushing impacts inflorescence mass disproportionately to vegetative mass because inflorescences are still growing at the time of harvest. The results from this study should provide a clearer understanding of potential consequences of flushing to inflorescence and cannabinoid yield.

Materials and Methods

Plant material and propagation. Two cultivars, THM Jack and Southern OG (The Hemp Mine, Fairplay, SC, USA), were evaluated. 'THM Jack' is an early-season cultivar that initiates inflorescences when exposed to a photoperiod $\leq$ 16 h and is typically harvested after 7 weeks in a 12-h photoperiod. Southern OG is a midseason cultivar that initiates inflorescences in a photoperiod $\leq$ 14 h and is typically harvested after 8 weeks in a 12-h photoperiod. Both cultivars are categorized as chemotype III, which is defined as CBD-dominant with a THC concentration $< 0.3\%$ (Jin et al. 2019).

One experiment was conducted and repeated twice. For each replication, 48 and 72 shoot-tip cuttings (6 cm in length) were collected from 'THM Jack' and 'Southern OG' (The Hemp Mine, Fairplay, SC, USA) stock plants, respectively, that were grown under a 21-h photoperiod. Each cutting stem was dipped in a rooting solution consisting of 3000 mg·L^{-1} naphthyl acetic acid. Cuttings were stuck in a 72-cell propagation tray loosely filled with a peat-based germination mix (Sunshine Mix #5; SunGro, Anderson, SC, USA) and moved to a shaded propagation greenhouse equipped with intermittent mist. Mist frequency was regulated with a controller (Water Pro II; MicroGrow, Temecula, CA, USA) that was programmed to mist cuttings for 6 s each time the accumulated vapor pressure deficit exceeded 2.0 kPa. Cuttings were provided with a photosynthetic photon flux density (PPFD) of 28.1 ± 3.0 μmol·m^{-2}·s^{-1} from 0500 HR to 0200 HR daily, resulting in a 21-h photoperiod from light-emitting diode lamps (Hawk Duo 2.0; Sananbio, Xiamen, China). The average daily temperature in propagation was 27.0 °C ±1.3 °C, and relative humidity averaged 60.1% ±11.7%.

Vegetative period. After 14 d in propagation, 48 and 72 rooted cuttings of 'THM Jack' and 'Southern OG', respectively, were transplanted into 2.5 L black plastic containers with a peat-based growing medium (Fafard 3B; Sun Gro, Anderson, SC, USA) and spaced on a greenhouse bench at a density of 36 plants/m^2. Cultivars were separated within the greenhouse bench and centered under light-emitting diode lamps (Hawk Duo 2.0; Sananbio, Xiamen, China) that delivered a PPFD of 390 ± 35 μmol·m^{-2}·s^{-1} from 0500 HR to 0200 HR daily resulting in a 21-h photoperiod. Plants were maintained under this photoperiod to provide 2 weeks of vegetative growth. Sunlight provided an average daily light integral of 26.8 ± 7.5 mol·m^{-2}·d^{-1} during this time. The daily light integral delivered during vegetative growth was approximately 56.3 ± 11.4 mol·m^{-2}·d^{-1}. The average daily temperature was 24.3 °C ± 2.3°C, and relative humidity averaged 80.4% ± 10.6%. Unless otherwise indicated, a continuous liquid fertilizer program of Peters Excel Cal-Mag Special (15N–2.2P–12.5K; JR Peters, Allentown, PA, USA) at 200 mg·L^{-1} N was provided for the duration of the study from transplant until harvest. At transplant, plants were pinched, leaving two nodes on the primary stem. The two secondary shoots were pinched to two nodes 1 week later. The four tertiary shoots were pinched to two nodes 1 week later. These three pinches resulted in 8 shoots/plant at the start of the 12-h photoperiod. The eight quaternary shoots were pinched to two nodes 1 week after starting the 12-h photoperiod, resulting in 16 shoots/plant for both cultivars. Based on previous research, multiple pinches can eliminate the need to provide physical support to developing shoots and reduce spatial variation of inflorescence mass and tissue concentration within a plant (Alden and Faust 2024; Danziger and Bernstein 2021).

Flowering period. Both cultivars were flowered in a greenhouse equipped with an automatic black-out system for photoperiod control. The black-out system opened at 0800 HR and closed at 2000 HR each day to provide a 12-h photoperiod. During this time, light-emitting diode lamps (GreenPower LED HO; Philips, Somerset, NJ, USA) delivered supplemental lighting with a PPFD of 522 ± 69 μmol·m^{-2}·s^{-1}. The total average daily light integral including both sunlight and supplemental lighting was 39.4 ± 6.9 mol·m^{-2}·d^{-1}. The average daily temperature was 23.1 °C ± 1.9 °C, and the relative humidity averaged 58% ± 16%.

Experiment design. The two cultivars differed in the number of flush-duration treatments and length of flowering period before plants were destructively harvested (Table 1). For 'THM Jack', four flush-duration treatments ranging from 0 to 3 weeks at 1-week intervals were tested, and all plants were harvested after 7 weeks in the 12-h photoperiod. For 'Southern OG', five flush-duration treatments from 0 to 4 weeks were tested, and all plants were harvested after 8 weeks in the 12-h photoperiod. The control group, i.e., the 0-weeks flush duration, received fertilizer for the entirety of the experiment, and the growing substrate was never flushed. At the start of 12-h photoperiod, 16 and 25 plants of 'THM Jack' and 'Southern OG', respectively, were selected for uniformity and then randomly assigned flush duration treatment labels. All plants were randomly distributed across a greenhouse bench at a density of 8 plants/m^2. Each flush-duration treatment consisted of four plants per cultivar, and each plant was considered a separate experimental unit. Each plant was considered a separate experimental unit because flush duration treatments were manually applied on a plant-by-plant basis and data were collected from each plant just one time (i.e., no subsampling occurred).

Flushing protocol. The flushing procedure consisted of applying tap water (0.1 mS·cm^{-1}) to the substrate until the leachate EC measured $\leq$ 0.2 mS·cm^{-1}, then irrigating with tap water as needed until harvest. Three drip emitters were placed on top of the substrate of each container, and tap water was delivered for at least 5 h. Each drip emitter delivered 1 L of water per hour. Leachate measurements were conducted using the pour-thru method (Mattson 2008) 30 to 60 min following termination of drip irrigation. If the leachate measured $>$ 0.2 mS·cm^{-1}, then plants were irrigated for 1 h, followed by another leachate measurement.

Plant measurements. At harvest, the primary stem of each plant was cut 2 cm above

Table 1. Cannabis 'THM Jack' and 'Southern OG' plants were flowered under a 12-h photoperiod for 7 or 8 weeks, respectively, and then destructively harvested for data collection. Flushing treatments were applied for 0 to 3 weeks before harvest in 'THM Jack' or 0 to 4 weeks in 'Southern OG'. The flushing protocol involved first reducing substrate electrical conductivity < 0.2 mS·cm^{-1} and then providing only clear water as needed until the end of the experiment. All plants received a liquid fertilizer solution with each irrigation event unless they were undergoing a flushing treatment. The 0-week flushing treatment was a control group that received fertilizer for the duration of the experiment, and the substrate was never flushed. + = fertilizer was provided with each irrigation; – = only tap water was provided.

		12-h photoperiod (wk)							
Cultivar	Flush duration (wk)	1	2	3	4	5	6	7	8
THM Jack	0	+	+	+	+	+	+	Harvest	
	1	+	+	+	+	+	–		
	2	+	+	+	+	–	–		
	3	+	+	+	–	–	–		
Southern OG	0	+	+	+	+	+	+	+	Harvest
	1	+	+	+	+	+	+	–	
	2	+	+	+	+	+	–	–	
	3	+	+	+	+	–	–	–	
	4	+	+	+	–	–	–	–	

the substrate. Reproductive and vegetative mass were separated, and the fresh mass of each was recorded. Reproductive mass was defined as the sum of lateral shoots that developed following the final pinch. These lateral shoots consisted of multiple inflorescences that were each subtended by a leaf with a petiole, and each inflorescence was separated by an internode that decreased in length up to the terminal inflorescence (i.e., the uppermost inflorescence lacking visible internodes). Vegetative mass was defined as the sum of the stems and leaves below the reproductive mass. Vegetative and reproductive dry mass were recorded after drying for 3 weeks in a growth room at 20 °C and 55% relative humidity.

Reproductive dry mass was further broken down into inflorescences and trim. An inflorescence was defined as a trimmed cluster of flowers resembling commercially acceptable smokeable product described colloquially as flower buds. Trim was defined as the sum of internodes, bracts, and small leaves separated from inflorescences when reproductive mass was broken down. For all dry mass responses, yield ($kg \cdot m^{-2}$) was calculated by multiplying mass measurements (g/plant) by planting density (8 plants/m^2). Harvest index was calculated as the ratio of inflorescence dry mass to total dry mass.

Dried inflorescences were ground to homogenize the mass into a powder from which 2 g samples were collected. The grinder was cleaned with isopropyl alcohol between samples. An elemental analysis of the ground inflorescence tissue was conducted using inductively coupled plasma optical emission spectroscopy (Clemson University Agricultural Service Laboratory, Clemson, SC, USA). The cannabinoid analysis was conducted using high-performance liquid chromatography (Kaycha Laboratories, Denver, CO, USA). Three samples per treatment were analyzed in each experimental replication for both cultivars. Cannabinoid concentrations were reported as a percent dry mass of the inflorescences. Tetrahydrocannabinol (THC) and cannabidiol (CBD) percentages were calculated as follows:

$$THC(\%) = (THCA \times 0.877) + \Delta\text{-}9\text{-}THC \quad \text{Eq. [1]}$$

$$CBD(\%) = (CBDA \times 0.877) + CBD \quad \text{Eq. [2]}$$

where THCA is tetrahydrocannabinolic acid, Δ-*9-THC* is delta-9-tetrahydrocannabinol, and CBDA is cannabidiolic acid. The masses of THC and CBD (g/plant) were calculated by multiplying inflorescence dry mass by the dry mass percentage for each cannabinoid within treatments. Then, these values were divided by planting density (8 plants/m^2) to calculate cannabinoid yield ($g \cdot m^{-2}$). Elemental tissue concentrations are reported as a percent dry mass of the inflorescence.

Data analysis. The analysis of the response variables (dry mass, cannabinoid concentration, etc.) was based on a statistical model that determined the impact of flush duration as a continuous variable using an analysis of variance (ANOVA). The *P* values associated with the tests were considered significant when $P < 0.05$. Regression curve fitting was conducted for the response variables affected by flush duration. For these responses, quadratic regression curves were fit only when the lack of fit test for linear regression was significant. Regression equations are presented in the Supplementary Materials. Statistical calculations were performed with JMP Pro (version 16.0; SAS Institute Inc., Cary, NC, USA). Data from both experimental replications were pooled for the data analysis, and the two cultivars were analyzed separately.

Results

Dry mass. Flush duration affected reproductive dry mass in both cultivars (Table 2). For 'THM Jack', an inverse linear relationship was found between flush duration and reproductive dry mass (Fig. 1). For example, reproductive dry mass averaged 0.29 $kg \cdot m^{-2}$ in the 0-week flush treatment and decreased 0.02 $kg \cdot m^{-2}$ each week thereafter. For 'Southern OG', reproductive dry mass declined as flush duration increased, but the relationship was nonlinear (Fig. 1). Reproductive dry mass was identical in the 0-week and 1-week flush treatments, but dry mass declined as flush duration increased longer than 1 week. For example, reproductive dry mass averaged 0.49 $kg \cdot m^{-2}$ in the 0-week and 1-week flush treatments and decreased to 0.37 $kg \cdot m^{-2}$ in the 4-week flush treatment. Flush duration affected vegetative dry mass in both cultivars and was similar to the response of reproductive dry mass within cultivar (Table 2, Fig. 1). For example, an

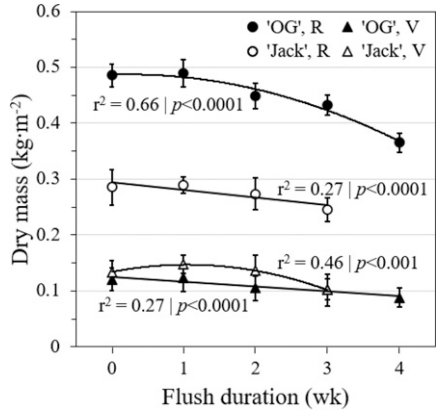

Fig. 1. Effect of flush duration on dry mass of cannabis 'THM Jack' and 'Southern OG', which were flowered under a 12-h photoperiod for 7 weeks or 8 weeks, respectively, and then destructively harvested for data collection. Before harvest, flushing treatments were applied to 'THM Jack' ('Jack') for 0 to 3 weeks or 'Southern OG' ('OG') for 0 to 4 weeks. Reproductive mass (R) was defined as the sum of all lateral shoot mass that developed under 12-h photoperiod following the final pinch. Vegetative mass (V) was defined as the sum of the stems and leaves below the reproductive mass. Error bars = ±1 standard deviation. Regression lines indicate significant responses. Regression equations are presented in the Supplementary Materials.

Table 2. Cannabis 'THM Jack' and 'Southern OG' were flowered under a 12-h photoperiod for 7 weeks or 8 weeks, respectively, and then destructively harvested for data collection. Before harvest, flush duration treatments were applied for 0 to 3 weeks in 'THM Jack' or 0 to 4 weeks in 'Southern OG'. Flush duration treatments were applied by leaching the growing substrate with tap water until leachate electrical conductivity measured < 0.2 $mS \cdot cm^{-1}$, followed by irrigating plants only with tap water as needed until harvest. The analysis of variance (ANOVA) output describes the significance of flush duration on mass measurements and calculations. Cannabinoid and mineral nutrient concentrations are calculated a percent dry weight of inflorescence mass.

	Flush duration (wk)			
	THM Jack		Southern OG	
Response	F-ratio and significance			
Reproductive dry mass ($kg \cdot m^{-2}$)	13.9	**	69.2	**
Vegetative dry mass ($kg \cdot m^{-2}$)	8.6	**	17.1	***
Inflorescence dry mass ($kg \cdot m^{-2}$)	18.3	**	58.4	***
Trim dry mass ($kg \cdot m^{-2}$)	0	NS	3.3	NS
Inflorescence:trim	11.5	**	2.4	NS
Harvest index	0.7	NS	0.2	NS
THC (%)	0.5	NS	0	NS
CBD (%)	0.6	NS	7.2	*
CBD:THC	0	NS	6.5	*
THC yield ($g \cdot m^{-2}$)	2.3	NS	37.5	***
CBD yield ($g \cdot m^{-2}$)	6.1	*	8.9	**
Nitrogen (%)	79.7	***	165.8	***
Phosphorus (%)	4.3	*	154.5	***
Potassium (%)	27.4	***	11.5	**
Calcium (%)	1.3	NS	57.4	***
Magnesium (%)	0.9	NS	0.9	NS
Sulfur (%)	0.7	NS	5	*
Iron (ppm)	5.2	*	15.7	**
Manganese (ppm)	1.2	NS	18.5	**
Zinc (ppm)	0.4	NS	5.8	*
Copper (ppm)	0.3	NS	143.7	***
Boron (ppm)	18.1	**	1.7	NS

NS, *, **, ***, nonsignificant or significant at $P < 0.05$, 0.01, or 0.0001, respectively.
CBD = cannabidiol; THC = tetrahydrocannabinol.

inverse, linear relationship was observed in 'Southern OG' between vegetative dry mass and flush duration, which averaged 0.12 kg·m^{-2} in the control group and declined at a rate of 0.01 kg·m^{-2}·wk^{-1}.

Inflorescence dry mass was impacted by flush duration in both cultivars (Table 2). For 'THM Jack', inflorescence dry mass averaged 0.17 kg·m^{-2} in the control group and decreased 0.01 kg·m^{-2}·wk^{-1} as flush duration increased (Fig. 2A). For 'Southern OG', inflorescence dry mass also declined as flush duration increased, but the relationship between these variables was nonlinear. Inflorescence dry mass averaged 0.40 and 0.36 kg·m^{-2} in the 0-week and 2-week flush treatments, respectively, which equated to a 10% decrease. In contrast, inflorescence dry mass decreased 22% as flush duration increased from 2 to 4 weeks. Therefore, flush durations $>$ 2 weeks were more impactful than those $\leq$ 2 weeks for 'Southern OG'. Trim dry mass was insensitive to flush duration in both cultivars (Table 2). Inflorescence:trim was affected by flush duration for 'THM Jack', but not for 'Southern OG' (Table 2). For 'THM Jack', inflorescence:trim decreased from 1.8:1 to 1.5:1 as flush duration increased from 0 to 3 weeks (Fig. 2C). No change in inflorescence:trim was found for 'Southern OG', which averaged 4.4:1 across all treatments (Fig. 2D). Harvest index was not impacted by flush duration in either cultivar (Table 2), which averaged 0.40 and 0.64 for 'THM Jack' and 'Southern OG', respectively.

Cannabinoids. In both cultivars, THC concentration within inflorescence tissue was unaffected by flush duration (Table 2). The THC concentration averaged 0.45% and 0.54% across all treatments for 'THM Jack' and 'Southern OG', respectively (Fig. 3A). The CBD concentration was affected by flush duration only for 'Southern OG' (Table 2), and a direct linear relationship was observed between these variables. For example, CBD concentration averaged 12.8% in the control group and increased by 0.5% with each week increase in flush duration (Fig. 3B).

Flush duration impacted THC yield in 'Southern OG', but not in 'THM Jack' (Table 2). The relationship between flush duration and THC yield was nonlinear in 'Southern OG'. The THC yield was greatest in the 1-week flush duration treatment, which averaged 2.2 g·m^{-2}, and gradually decreased to 1.6 g·m^{-2} in the 4-week flush treatment (Fig. 4A). Flush duration impacted CBD yield in both cultivars (Table 2), which resulted in a linear decrease of CBD yield as flush duration increased. For 'THM Jack', CBD yield averaged 19.3 g·m^{-2} in the control group and decreased 1.2 g·m^{-2}·wk^{-1} (Fig. 4B). For 'Southern OG', CBD yield averaged 50.7 g·m^{-2} and decreased 1.8 g·m^{-2}·wk^{-1}.

Elemental nutrient concentration. Mixed responses were observed with increasing flush duration depending on the cultivar and elemental nutrient of interest. Nitrogen, phosphorus, and potassium concentration were affected by the flush duration in both cultivars (Table 2). For all three responses, maximum tissue concentration occurred in the control group and decreased linearly as flush duration increased (Fig. 5A–C). For example, the phosphorus concentration averaged 1.2% and 1.1% in the control group for 'THM Jack' and 'Southern OG', respectively, and decreased 0.09% with each week increase in flush duration in both cultivars (Fig. 5B). The calcium concentration was affected by flush duration in 'Southern OG', but not in 'THM Jack' (Table 2). The calcium concentration averaged 1.2% in both the 0 week and 1 week flush treatments and increased to a maximum of 1.7% as flush duration increased to 4 weeks (Fig. 5D). The magnesium concentration was unaffected by the flush duration in either cultivar (Table 2); across flushing treatments, the magnesium concentration averaged 0.63% and 0.61% for 'THM Jack' and 'Southern OG', respectively (Fig. 5E). For the sulfur concentration, only 'Southern OG' was affected by flush duration (Table 2). The sulfur concentration was lowest in the control group at 0.23% and increased 0.01% with each week increase in flush duration (Fig. 5F). For the elemental micronutrient concentrations, only iron and boron concentrations were affected in 'THM Jack' (Table 2). For both iron and boron, the maximum

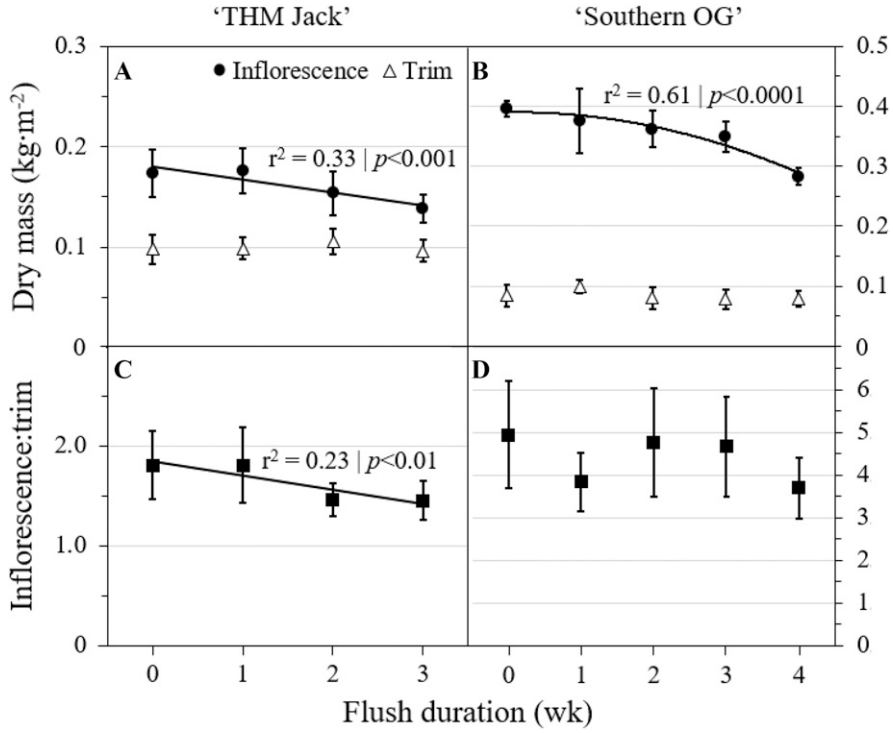

Fig. 2. Effect of flush duration on inflorescence and trim dry mass (**A**, **B**) and inflorescence:trim (**C**, **D**) on cannabis 'THM Jack' and 'Southern OG', which were flowered under a 12-h photoperiod for 7 weeks or 8 weeks, respectively, and then destructively harvested for data collection. Before harvest, flushing treatments were applied for 0 to 3 weeks in 'THM Jack' or 0 to 4 weeks in 'Southern OG'. Inflorescence was defined as trimmed clusters of flowers resembling a commercially acceptable smokeable product. Trim was defined as the sum of internodes, bracts, and small leaves that were separated from the inflorescences. Error bars = ±1 standard deviation. Regression lines indicate significant responses, while no regression line indicates a nonsignificant relationship. Regression equations are presented in the Supplementary Materials.

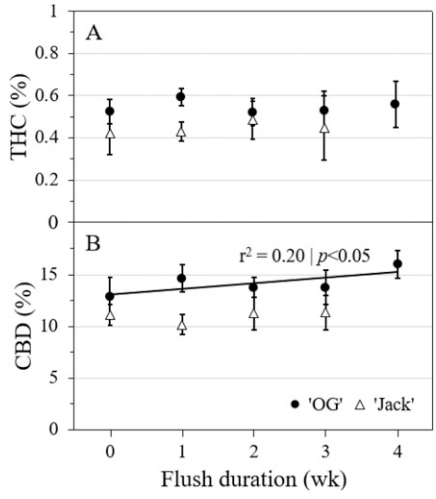

Fig. 3. Effect of flush duration on tetrahydrocannabinol (THC) (**A**) and cannabidiol (CBD) (**B**) concentration in inflorescence samples for cannabis 'THM Jack' ('Jack') and 'Southern OG' ('OG'), which were flowered under a 12-h photoperiod for 7 weeks or 8 weeks, respectively, and then destructively harvested for data collection. Before harvest, flushing treatments were applied for 0 weeks to 3 weeks in 'THM Jack' or 0 to 4 weeks in 'Southern OG'. Dried inflorescence mass was ground in a coffee grinder from which 2 g samples were collected and analyzed. Cannabinoid concentrations of inflorescence samples are presented as a percentage of dry mass. Error bars = ±1 standard deviation. Regression lines indicate significant responses, while no regression line indicates a nonsignificant relationship. Regressionequations are presented in the Supplementary Materials.

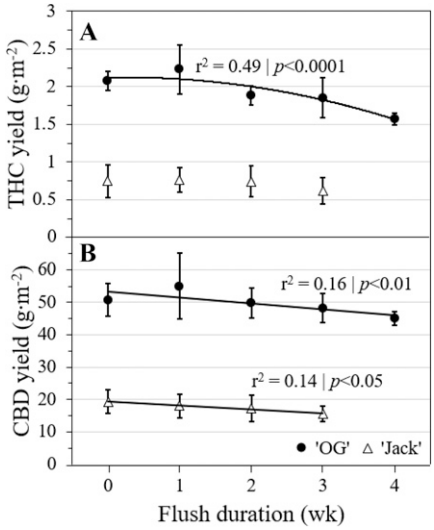

Fig. 4. Effect of flush duration on tetrahydrocannabinol (THC) (**A**) and cannabidiol (CBD) (**B**) concentrations in inflorescence samples for cannabis 'THM Jack' ('Jack') and 'Southern OG' ('OG'), which were flowered under a 12-h photoperiod for 7 weeks or 8 weeks, respectively, and then destructively harvested for data collection. Before harvest, flushing treatments were applied for 0 to 3 weeks in 'THM Jack' or 0 to 4 weeks in 'Southern OG'. Dried inflorescence mass was ground in a coffee grinder from which 2 g samples were collected and analyzed using high-performance liquid chromatography. The THC and CBD mass (g/plant) were calculated by multiplying inflorescence dry mass by the average percent dry mass for each cannabinoid within treatments. These values were then divided by planting to calculate cannabinoid yield ($g \cdot m^{-2}$). The THC and CBD correspond to tetrahydrocannabinolic acid (THCA) and cannabidiolic acid (CBDA) concentrations, respectively. Error bars = ±1 standard deviation. Regression lines indicate significant responses. Regression equations are presented in the Supplementary Materials.

concentration occurred in the control group and decreased linearly as flush duration increased (data not shown). For 'Southern OG', iron, manganese, zinc, and boron concentrations, but not the copper concentration, were affected by flush duration (Table 2). As with 'THM Jack', the maximum concentration occurred in the control group and generally decreased as the flush duration increased (data not shown).

Discussion

A flush duration of just 1 week impacted inflorescence mass as well as the tissue concentration of cannabinoids and mineral nutrients in both tested cultivars. The decision to flush during cannabis production should consider that a desired outcome (e.g., reduce fertilizer cost, manipulate tissue concentrations, improve smoking quality) may come at the expense of dry mass and, ultimately, yield.

We found that increasing the flush duration was antagonistic toward reproductive, inflorescence, and vegetative dry mass in both cultivars. Earlier research involving 'Southern OG' showed that most growth occurs in the developing reproductive shoots by the fourth week after starting the 12-h photoperiod (Alden and Faust 2025). In this study, flushing treatments were applied between 4 and 8 weeks after starting the 12-h photoperiod; therefore, the decline in reproductive and inflorescence dry mass was expected. In general, nutrient limitation during growth periods will reduce dry mass (Fischer and Evans 1999). We assumed that both inflorescence and trim dry mass would decline in response to increasing flush duration, but the homogeneity of trim dry mass measurements among flush duration treatments in each cultivar suggest that flushing specifically restricts inflorescence growth within the developing reproductive shoots. Earlier research by Stemeroff (2017), Wedryk (2019), and Saloner et al. (2024) indicated that flushing was inconsequential to inflorescence mass, but our findings differed and, at minimum, indicated cultivar-based sensitivity. Furthermore, our flushing protocols ensured that substrate EC was minimized on the first day when flushing treatments began, which means that nutrient limitations were imposed immediately. Stemeroff (2017) and Wedryk (2019) did not report any leachate measurements. Saloner et al. (2024) noted that leachate EC measured 0.37 $mS \cdot cm^{-1}$ on the third day after flushing treatments began, which was nearly double that of what was provided to plants on the first day of flushing treatments in this study. Therefore, the negligible impact of flushing on dry mass measurements reported by Stemeroff (2017), Wedryk (2019), and Saloner et al. (2024) suggested that sufficient nutrient concentrations were available in the growing substrate to sustain growth in these studies and that their flush duration treatments do not reflect the duration that plant growth was restricted by nutrient availability in the substrate.

The EC of the water used to leach the growing substrate will impact the target substrate EC when flushing. Ensuring that the tap water EC is sufficiently low to leach the substrate may require adding filtration systems. In this study, tap water EC measured $\leq$ 0.1 $mS \cdot cm^{-1}$, which was essential in dropping substrate EC $\leq$ 0.2 $mS \cdot cm^{-1}$. Similarly, the fertilizer program will likely affect the flush duration results. Fertilizer programs on the leaner side, such as that recommended by Utah State University (Langenfeld and Bugbee 2024), will rapidly induce nutrient disorders when flushing treatments begin. In contrast, fertilizer programs on the heavier side that permit luxurious nutrient uptake will likely require longer flush durations to observe signs of nutrient disorders. Thus, the source water and fertilizer program must be considered together when evaluating flush durations necessary to achieve a given production goal.

Vegetative dry mass decreased as flush duration increased; these differences are explained by lower leaf abscission that increased in magnitude with flush duration. For 'Southern OG', symptoms consistent with prolonged nitrogen deficiency were evident, which included leaf chlorosis progressing to marginal necrosis and, finally, leaf abscission (Fig. 6). For 'THM Jack', similar symptoms were evident, but leaves tended to exhibit orange and purple hues before necrosis and abscission (Fig. 7). Inducing lower leaf abscission with flushing could benefit growers by forcing plants to discard foliage that is often infected with powdery mildew and contributes little toward photon capture because of intracanopy and intercanopy competition for light (Scott and Punja 2020). Inducing lower leaf abscission might also benefit growers by reducing vapor load on dehumidification equipment in drying areas, which means space and energy are not invested in drying plant material that contribute little or no economic value. These potential benefits are achieved at the expense of both inflorescence and cannabinoid yield, which might be tolerable if production efficiency improved and overall profitability was not impacted.

As a means for lowering fertilizer cost, flushing is appealing to growers that apply cannabis-specific fertilizers at excessive concentrations; however, flushing to reduce fertilizer cost is inefficient and reflects poor fertilizer management decisions. For example, the US Cannabis Spot Index indicated that 1 kg of dried trimmed inflorescences was valued at approximately $1958 in Jan 2025 (Hildenbrand and Mendoza-Dickey 2025). If we use 'Southern OG' to model revenue loss, then we expect that a 1-week flush duration reduces revenue by $39/$m^2$ relative to the 0-week control. If a cannabis grower uses the same fertilizer blend ($40 per 55 kg bag) and concentration (200 $mg \cdot L^{-1}$ N), as done in this study, along with providing 500 mL fertilizer solution daily to each plant at a planting density of 8 plants/m^2, then a 1-week flush duration will reduce fertilizer cost by $0.13/$m^2$. A revenue loss of approximately $297 is expected per $1 saved on fertilizer, which is not an acceptable tradeoff in commercial production systems; fertilizer cost, concentration, and solution volume applied must increase to unreasonable levels to approach an equivalent tradeoff.

Rather than flushing, cannabis growers might consider replacing cannabis-specific fertilizers with low-cost alternatives, such as the fertilizer blends commonly used in the greenhouse floriculture industry, as well as providing fertilizer rates that are in line with plant demand, which together result in fertilizer accounting for a small fraction of annual production cost (Hall 2022). A recent study found that common floriculture fertilizer blends like 13–2–13 and 17–4–17 were acceptable as an all-in-one product for cannabis growth (Whipker et al. 2024). Furthermore, recent studies have demonstrated that adequate growth is sustained with fertilizer concentrations substantially lower than those typically provided in commercial production (Bernstein et al. 2019; Langenfeld et al. 2022; Massuela et al. 2022; Shiponi and Bernstein, 2021; Westmoreland and Bugbee 2022). When fertilizer cost is low, potential cost savings with flushing are negligible relative to potential yield losses of high-

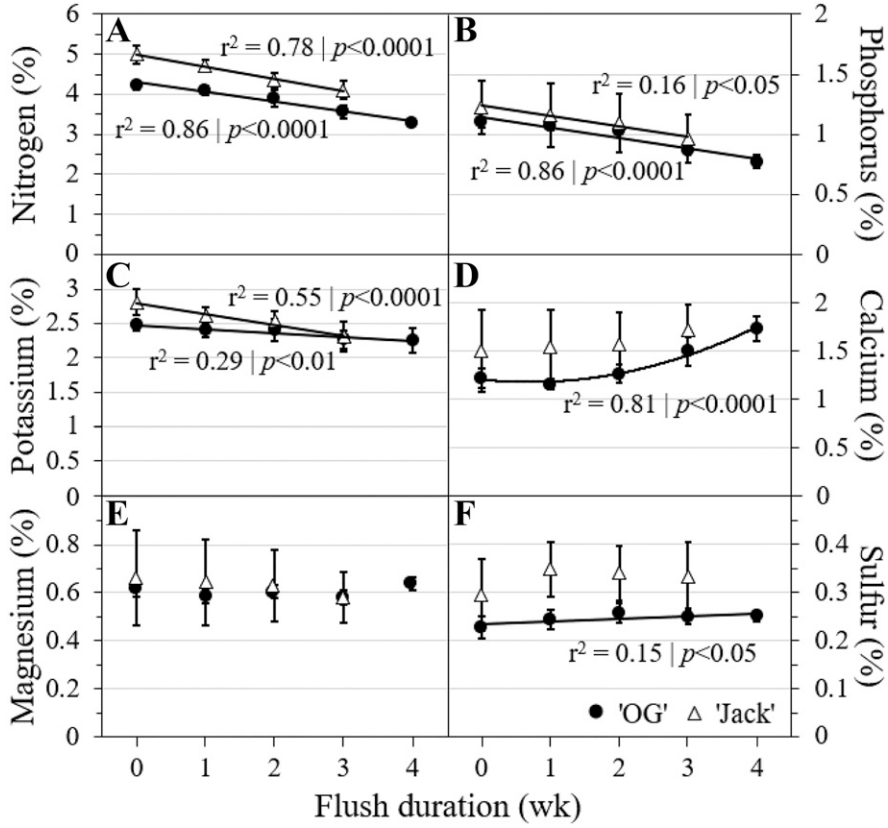

Fig. 5. Effects of flush duration on nitrogen (**A**), phosphorus (**B**), potassium (**C**), calcium (**D**), magnesium (**E**), and sulfur (**F**) concentrations in inflorescence samples of cannabis 'THM Jack' ('Jack') and 'Southern OG' ('OG') that were flowered under the 12-h photoperiod for 7 or 8 weeks, respectively, and then destructively harvested for data collection. Before harvest, flushing treatments were applied for 0 to 3 weeks in 'THM Jack' or 0 to 4 weeks in 'Southern OG'. Dried inflorescence mass was ground in a coffee grinder from which 2 g samples were collected and analyzed. Data are reported as a percentage dry mass of inflorescence samples. Error bars represent ±1 standard deviation. Regression lines indicate significant responses, while no regression line indicates a nonsignificant relationship. Regression equations are presented in the Supplementary Materials.

value products like trimmed inflorescences. Therefore, flushing is not recommended as a strategy for lowering fertilizer cost; instead, both the source and rate of fertilizer applied should be re-evaluated.

The origin of flushing is unknown, but we suspect that flushing was devised as a method to mitigate symptoms of salt stress (e.g., stunted growth, tissue necrosis, wilting) induced by excessive fertilization during cannabis production. Salts accumulate in the growing substrate when the fertilizer concentration provided exceeds plant demand, leading to high substrate EC. Leaching with clear water to reduce substrate EC is a standard practice in controlled-environment production of many ornamental crops (Whipker et al. 2018), but only as a means to correct imbalances between the fertilizer concentration provided and plant demand. In cannabis production, it appears substrate leaching was termed "flushing" and uniquely viewed as a technique to improve final product quality. Flushing as a remedy to salt stress may have later been interpreted as an improvement in inflorescence quality. If fertilizer rates are in line with plant demand, then flushing is unnecessary to avoid salt stress symptoms.

Fig. 6. Visual impact of flush duration on 'Southern OG' applied for 0 to 4 weeks before harvest. All treatments were flowered under a 12-h photoperiod for 8 weeks and then destructively harvested for data collection. The photograph was taken immediately before data collection. The 0-week flush duration was an untreated control that received a continuous liquid fertilizer program for the duration of the experiment.

Flush duration did not impact the THC or CBD concentration in 'THM Jack', but the CBD concentration increased with flush duration in 'Southern OG'. Although this response in 'Southern OG' is consistent with the yield dilution (Fan et al. 2008; Wang et al. 2018), nitrogen deprivation was reported to induce a metabolic shift that stimulates greater synthesis of secondary metabolites, including THC and CBD (Song et al. 2023). In either case, the capacity to manipulate the cannabinoid concentration with flushing could have some benefit in markets where product value is directly tied to cannabinoid concentration, which is common across the United States because consumers often assume that cannabinoid concentration and product quality are directly related (Roberts 2020). The correlation between cannabinoid concentration and product value has led to cannabis growers sending inflorescence samples to multiple analytical laboratories and "shopping" for higher results for labeling purposes (Schwabe et al. 2023). However, the existing relationship between cannabinoid concentration and product value is likely temporary because recent work has shown that consumer preferences change

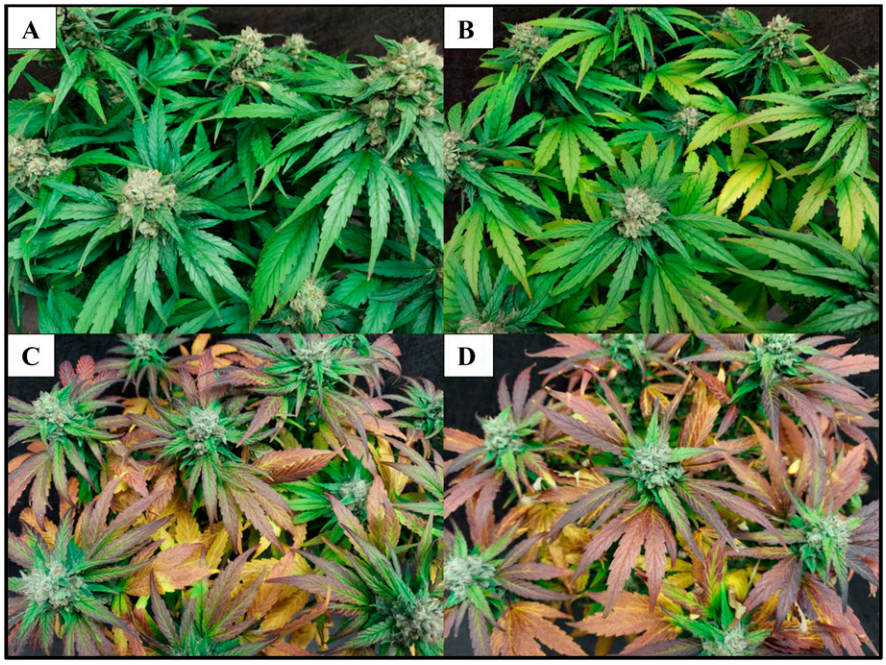

Fig. 7. Visual impact of flush duration on 'THM Jack' applied for 0 weeks (**A**), 1 week (**B**), 2 weeks (**C**), or 3 weeks (**D**) before harvest. All treatments were flowered under a 12-h photoperiod for 7 weeks and then destructively harvested for data collection. The photograph was taken immediately before data collection. The 0-week flush duration treatment (**A**) was an untreated control that received a continuous liquid fertilizer program for the duration of the experiment.

when cannabinoid concentration is unknown to them (Plumb et al. 2022). Furthermore, CBD yield declined in response to increasing flush duration, which means that the increase in CBD concentration observed in 'Southern OG' did not compensate for the decline in inflorescence dry mass. Therefore, flushing is not recommended as a means to manipulate cannabinoid concentration because this change will likely come at the expense of dry mass and cannabinoid yield.

Our results show that flushing can impact elemental micronutrient and macronutrient tissue concentrations, but the response varies by cultivar and nutrient of interest. Research of other crops has demonstrated that changes in fertilizer application and mineral nutrient concentrations can alter pest and disease susceptibility, which could have practical value for growers because few pesticides are currently labeled for use on cannabis. We found that nitrogen concentration in inflorescence tissue decreased in both cultivars as flush duration increased; lower nitrogen application and tissue concentration reduced infestation of citrus mealybug in coleus (*Solenostemon scutellarioides*) (Hogendorp et al. 2006), whitefly in okra (*Hibiscus esculentus*) (Athar et al. 2011) and tomato (*Lycopersicon esculentum*) (Jauset et al. 2000), stem borer in rice (*Oryza sativa*) (Aziz et al. 2018), and oriental fruit moth in nectarine (*Prunus persica*) (Daane et al. 1995). Because our flushing protocols can reduce nitrogen tissue concentration and provides an opportunity to reduce nitrogen application, mitigating population growth of common cannabis pests like aphids, western flower thrips, and two-spotted spider mites might be possible (Lemay et al. 2022). However, phosphorus and potassium tissue concentrations also declined in response to increasing flush duration. Plants deficient in these nutrients are more susceptible to pests and pathogens and, thus, might counteract any benefit achieved with reduced nitrogen application if all nutrients are simultaneously restricted (Gómez-Trejo et al. 2021).

For 'Southern OG', the calcium concentration increased with flush duration, which might lower inflorescence susceptibility to infection by *Botrytis*. In ornamental crops like petunia (*Petunia* spp.) and rose (*Rosa* spp.), the higher tissue concentration of calcium reduced *Botrytis* blight incidence and severity (Bennett et al. 2020; Muñoz et al. 2025). Especially in the summer months when high humidity is unavoidable in regions such as the southeastern United States, potential yield losses caused by flushing might be lower than losses caused by *Botrytis* blight if the higher calcium tissue concentration did, indeed, reduce inflorescence susceptibility to *Botrytis* infection in cannabis.

Improvements in inflorescence smoking quality via flushing are unsubstantiated in the literature, but we suspect that the organoleptic characteristics of dried inflorescences might differ when harvested from cannabis plants subjected to prolonged nutrient stress relative to those harvested from plants provided an adequate fertilizer program. We found that the sulfur concentration increased with flush duration in 'Southern OG'; sulfur-containing compounds are linked to "skunky" or "rotten egg" odors that are highly desirable by cannabis consumers (Oswald et al. 2023). Whether this increase in sulfur tissue concentration directly correlates to an increase in these same desirable sulfur-containing compounds is unclear, but the protocols developed in this study provide a means to investigate this subject further. Some changes in elemental micronutrient concentrations were observed in both cultivars, but these changes were generally small and likely do not impact inflorescence development to the degree that changes in macronutrient concentrations will. The potential benefits associated with altering mineral nutrient tissue concentrations are purely speculative at this stage, and substantial work is needed in these areas before conclusions are drawn about how flushing impacts either pest and disease susceptibility or inflorescence smoking quality.

Conclusions

The results of this study demonstrate that flushing can be a detrimental practice depending on the flush duration, cultivar, and parameter of interest. The decision to flush during cannabis production should weigh the tradeoff of a desired outcome (e.g., reduce fertilizer cost, manipulate tissue concentrations, improve smoking quality) against the potential loss of inflorescence and cannabinoid yield. Flushing protocols that thoroughly leach the growing substrate, as done during this study, are fiscally and environmentally irresponsible and should not be used in commercial production without targeting a specific outcome. We found that approximately 15 L of tap water ($\leq$ 0.1 mS·cm^{-1}) was necessary to achieve $\leq$ 0.2 mS·cm^{-1} leachate in a 2.5 L container, which discards nutrients that could otherwise benefit plant growth and, thus, wastes water, fertilizer, and, ultimately, money. If a cultivar demonstrates insensitivity to a specified flush duration before harvest, then eliminating fertilizer from the irrigation solution could be considered a sustainable production strategy to reduce fertilizer input and minimize nutrient runoff during cannabis production. However, further work is needed to validate this approach, especially during controlled-environment greenhouse production where environmental conditions can vary seasonally and might impact cultivar sensitivity to flush duration.

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