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Effect of Soil Moisture Tension and Soil Water Content on the Growth of Chrysanthemum in 3 Container Media

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Abstract. **No differences in final height, top fresh weight, top dry weight, or flower number were observed in *Chrysanthemum morifolium* Ramat. 'Spice' grown in 16.5-cm azalea pots when allowed to dry to soil moisture tensions of 5, 10, 20, or 30 kPa between waterings. Differences did occur in these parameters among the 3 tested media. Differences also occurred across all 3 media based on the volume of water remaining in the pot prior to watering. Plants growing in media containing more than 500 ml water just prior to irrigation had increased growth compared to plants in media containing less than 500 ml water. Cubic regression models were used to describe the percentage of moisture in the pot at soil moisture tensions between 0 and 30 kPa. The model may be used to predict container capacity and air space for most container sizes.**

The relationship between soil moisture tension (SMT) and plant growth has been studied to help determine guidelines for irrigation management. Research has concentrated on field grown crops such as avocado (20), citrus (9, 14, 19), sugar cane (3), and tomato (22). The relationship between SMT and plant growth is affected by many factors (20), but in general, water is not equally available over the range from field or container capacity to permanent wilting. Tensiometers have been used successfully to monitor SMT in both field (3, 9, 14, 19, 20, 26) and container studies (11, 13, 15, 16, 18, 24).

In container crop production, studies conducted to date have reported reduced plant growth as SMT increased (4, 12, 16). Hanan (10) concluded that carnations should be grown at SMT close to saturation (0 kPa) for optimum yields, provided other factors are not limiting. Havis (11) and Richards et al. (18) recommended irrigating ornamental plants when SMT levels reach 20 and 30 kPa, respectively, to avoid water stress. Spomer et al. (24) controlled soil water content and reported that bench-grown cut flower chrysanthemum growth increased as soil water content increased, except for the wettest treatment (8-cm soil depth). Spomer also explained that the shallowness of containers leads to excess water content and poor drainage, whereas small container size limits total water supply (25).

Amendments to media affect water supply because physical properties are generally altered to increase aeration at the expense of water holding capacity (24). The small size of a container also limits the water supply, because the water volume available to a plant in a container, larger in respect to another container, will be greater at any SMT. Therefore, the volume of water available in different media in the same container size may affect plant growth differently. The relationship between water content, SMT, and plant growth are important to irrigate container crops efficiently. The purposes of this study were to determine the effects of SMT, water content, and medium type on the growth of chrysanthemum 'Spice'.

Materials and Methods

On 19 Apr. 1983, 'Spice' plants were potted using 5 cuttings/16.5 cm azalea pot. Three media (bark-, soil-, and peat-based), representing a range of basic greenhouse mixes, were used (Table 1). The bark, soil, and peat media were amended with 8.3, 5.9, and 5.3 $kg \cdot m^3$ dolomitic limestone, respectively. All media were also amended with $0.9 \cdot kg \cdot m^3$ superphosphate (ON–19.8P–OK) and 73.9 $g \cdot m^3$ Peters Fritted Trace Elements No. 503.

Table 1. Mean height after 4 and 9 weeks, top fresh weight, top dry weight, and flower number for *Chrysanthemum morifolium* 'Spice by medium.

Medium type[z]	Ht (cm) 4 wks	Ht (cm) 9 wks	Wt of tops (g) Fresh	Wt of tops (g) Dry	Flower no.
Bark	6.6 a[y]	33.7 b	381.6 b	85.2 c	156 b
Soil	6.1 c	34.3 b	472.9 b	92.3 b	172 a
Peat	6.4 b	36.1 a	507.9 a	99.6 a	175 a

[z]Bark medium contained: 3 composted pine bark (<13 mm), 1 Canadian sphagnum peat moss (<6 mm), 1 concrete grade sand (v/v).
Soil medium contained: 1 Cecil clay loam (<6 mm), 1 Canadian sphagnum peat moss (<6 mm), 1 sand (v/v).
Peat medium contained: 1 Canadian sphagnum peatmoss (<6 mm), 1 horticultural grade vermiculite no. 1 (v/v).
[y]Mean separation in columns by Waller–Duncan K ratio *t* test. K ratio = 100.

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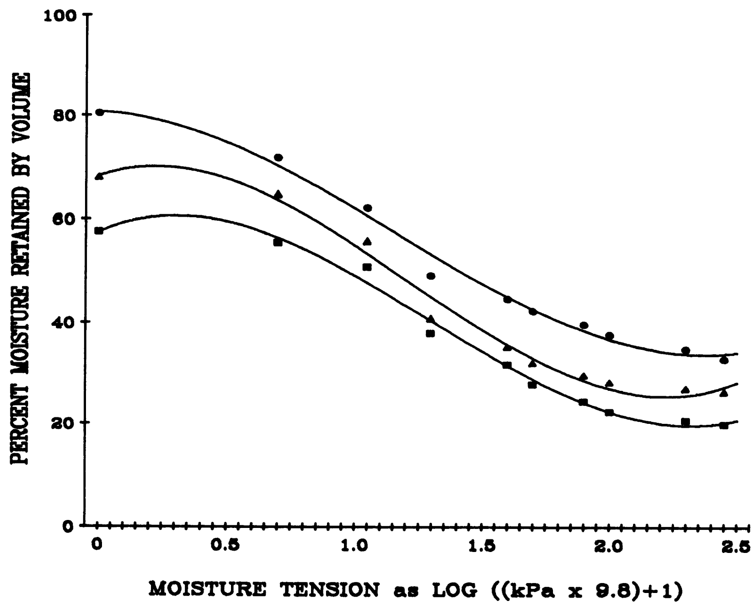

Fig. 1. Predicted moisture retention curves and cubic regression equations used to derive them for 3 media. ● = peat medium; ◆ = bark medium; ■ = soil medium. Points indicated by symbols are the experimentally determined values. See Table 1 for media descriptions.

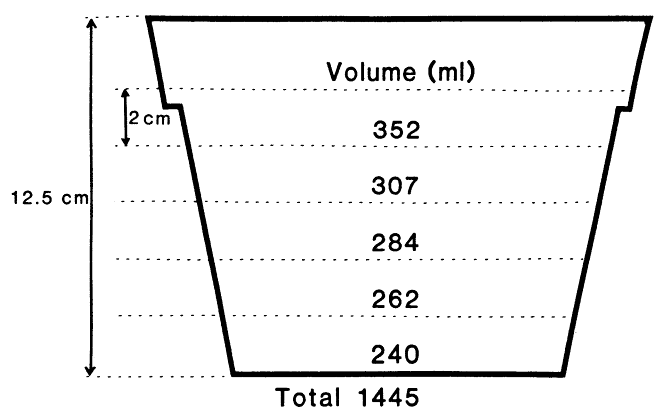

Fig. 2. Schematic representation of a 16.5-cm azalea pot showing how the pot was divided and the volume of each zone.

Long days were provided for one week, from 2200 to 0200 HR, using night interruption lighting procedures (15). All plants were pinched 2 weeks after potting.

The experimental design was a randomized complete block with 12 treatments and 8 blocks for 96 experimental units. Treatment design was factorial (3 media by 4 watering regimes). A watering regime was defined as an irrigation treatment in which the medium was allowed to dry to a defined SMT before water was applied to restore the root zone to container capacity (26). The watering regimes used allowed the media to dry to 5, 10, 20, or 30 kPa SMT prior to watering. A mercury manometer tensiometer system was used to monitor SMT. One tensiometer cup (length = 2.9 cm) was inserted into each pot so that the vertically oriented cup was halfway between the bottom of the pot and the top of the medium.

All plants were hand-watered as needed for the first 3 weeks, providing time to allow root systems to permeate the media adequately and to ensure that all tensiometers were functioning. Subsequently, each pot was watered when the SMT came within 10% of the desired SMT value for a given treatment. A preliminary experiment had shown that it was not feasible, under the given greenhouse conditions, to water the treatments as a block (13). Watering treatments were imposed 10 May 1983. The SMT and date were recorded at each watering. N and K were applied with every watering using technical grade KNO_3 and NH_4NO_3 to obtain 210 mg·liter^{-1} N and 195 mg·liter^{-1} K. A 2:1 (v/v) ratio of NO_3^- to NH_4^+ was used.

Plants were harvested 18 June 1983. Plant height (from rim of pot to base of flower), top fresh weight, top dry weight, and flower number were recorded for each pot. Foliar (whole plant top including flowers) and soil nutrient analyses were conducted for N, P, K, Ca, Mg, Fe, Cu, Zn, and Mn. Plant height and foliar analyses were also determined 4 weeks after potting.

Media water retention characteristics were determined using the pressure plate system described by Fonteno et al. (6). Media cores were prepared for the study using packing procedures described by Bilderback et al. (2). A model predicting the relationship between the percentage of soil water content and SMT (Fig. 1) was used to calculate total porosity, container capacity, and air space for each medium in a 16.5-cm azalea pot. The model equations are cubic regressions of semilogged data used to predict the percentage of water at SMT values between 0 and 30 kPa.

To accurately calculate the container capacity and air space for each medium, the pot was transversely sectioned into 2-cm zones (Fig. 2). It was important to section the pot to account for the influence of pot height and medium volume when estimating the amount of drainage occurring between saturation and container capacity. The volume used was corrected for medium shrinkage and did not represent the total volume of the pot. The model equations were used to predict the percentage of water values at 1, 3, 5, 7, and 9 cm depths (the midpoints of the 5 zones) for each medium.

Multiplying the percentage of water value by the volume of each zone gave the water volume held in each zone at container capacity. The water volume held in each zone was then summed

Table 2. Foliar nutrient analysis for *Chrysanthemum morifolium* 'Spice' at 4 weeks after potting and at flowering in 3 media.

Medium type[z]	Foliar nutrient analysis: Dry weight (%) N	P	K	Ca	Mg	PPM Fe	Mn	Zn	Cu
				Leaf sample[y]					
Bark	5.85	0.37	4.23	0.79	0.43	80	27	81	13
Soil	6.06	0.52	4.14	0.74	0.45	84	60	70	14
Peat	6.27	0.49	4.36	0.81	0.45	84	148	71	14
				Whole top sample[x]					
Bark	2.54	0.14	3.49	0.66	0.27	52	29	55	7
Soil	3.00	0.24	3.64	0.67	0.34	70	64	73	8
Peat	2.81	0.24	3.66	0.66	0.32	55	101	65	7

[z]See Table 1 for media descriptions.
[y]Leaf sample using youngest fully expanded leaf 4 weeks after potting.
[x]Whole plant top sampled at flowering.

Table 3. Percentage by volume of water released at 0 kPa[z] soil moisture tension, and percentage by volume held between 0 and 1, 1 and 5, 5 and 10, 10 and 20, 20 and 30, 5 and 30 kPa soil moisture tension and bulky density (BD) for 3 container media.

Medium type[y]	Water released (% by volume) at soil moisture tension (kPa) 0	0–1	1–5	5–10	10–20	20–30	5–30	Bulk density (g/cm^3)
Bark	68.6	12.2	24.0	3.9	1.2	0.7	5.8	0.503
Soil	58.7	6.3	21.9	6.2	2.4	1.2	9.8	1.048
Peat	83.4	18.9	20.5	4.8	3.0	2.0	9.8	0.202

[z]1 kPa = 10.2 cm of H_2O = 0.01 bars.
[y]See Table 1 for media descriptions.

Table 4. Mean height after 4 and 9 weeks, top fresh weight, top dry weight, and flower number for *Chrysanthemum morifolium* 'Spice' by minimum soil water content at watering in a 16.5 cm azalea pot.

Minimum water content[z] (ml)	Ht (cm) 4 wks	9 wks	Wt of tops (g) Fresh	Dry	Flower no.
301–400	6.3 a[y]	33.9 a	432 a	89 a	167 a
401–500	6.5 a	34.5 ab	438 b	90 a	166 a
501–600	6.2 a	36.1 c	503 c	99 b	177 ab
601–700	6.4 a	35.6 bc	533 d	101 b	180 b

[z]301–400: Treatments in this range: bark media watered at 20 and 30 kPa soil moisture tension (SMT). Soil media watered at 10, 20, and 30 kPa SMT.
401–500: Treatments in this range: bark media watered at 5 and 10 kPa SMT. Soil media watered at 5 kPa SMT. Peat media watered at 30 kPa SMT.
501–600: Treatments in this range: peat media watered at 10 and 20 kPa SMT.
601–700: Treatments in this range: peat medium watered at 5 kPa SMT.
(See Table 1 for media descriptions).
[y]Mean separation in columns by Waller–Duncan K ratio *t* test. K ratio = 100.

Table 5. Predicted total porosity (TP), container capacity (CC), and air space (AS) values for 3 media in 16.5 cm azalea containers.

Medium type[z]	Percent TP	CC	AS
Bark	69.0	62.3	6.7
Soil	58.4	57.0	1.4
Peat	83.8	71.1	12.7

[z]See Table 1 for media descriptions.

to give the total water volume in the pot at container capacity. Dividing the water volume at container capacity by the total volume of the 5 zones gave the percentage of water in the pot at container capacity.

Air space was determined by subtracting the percentage of water at container capacity from the percentage of water at total porosity (values for each medium are listed in Table 5). Total saturated volume of the pot was determined by multiplying the total porosity values by the medium volume in the pot. The difference between the saturated volume and the container capacity volume was the volume occupied by air at container capacity.

The volume of media in a pot was also used to calculate the volume of water remaining in each medium at the SMT limits used in the 4 watering regimes. Treatments were then grouped by water content contained prior to watering and analyzed for group differences using the growth parameters previously described.

Results and Discussion

The relationship between percent soil–water volume and SMT is shown in Fig. 1 (note the small relative change in the percentage of soil moisture at moisture tensions greater than 5 kPa). The symbols in Fig. 1 represent data points, whereas each line is predicted using the model equation shown for each medium. The model tends to underestimate the 20-kPa value and overestimate the 30-kPa value; however, the difference between the observed values and the predicted values is only 2% to 3%. It is important to note that the X value used in the model is the log of the SMT (or pF) in cm of water plus one. (One was added because the log of 0 is undefined). The model has 2 advantages over previous methods of presentation. First, it provides a mathematical prediction of the percentage of water volume at any SMT level in the 0 to 30 kPa range. Second, it can be used to make predictions for container capacity and air space for a range of container sizes.

High-quality chrysanthemums were produced with all media and SMT regimes. Table 1 lists height at 4 and 9 weeks, fresh weight, dry weight, and flower number for treatment groups by medium. After 4 weeks, the plants in the bark medium were taller than in the other media. The 9-week data show the peat medium plants grew larger and heavier with more flowers compared to those in the bark medium. The plants in the soil medium, which initially were the shortest, had a taller final height and greater fresh weight than the bark medium plants. The soil medium plants had a flower number similar to the peat medium plants.

Four weeks after planting, foliar analysis indicated sufficient nutrient levels (5) in all treatments (Table 2). Final foliar analysis results (Table 2) showed that the phosphorus levels in the bark medium appeared to be low toward the end of the experiment.

Growth parameters showed no difference when treatments were grouped by SMT regime. This observation is not in agreement with that of others who have investigated the effects of SMT on the growth of chrysanthemum (8, 21, 24, 27).

Reasons why no SMT differences were observed may be postulated using data from the pressure plate apparatus. Table 3 lists the percentage of volume attributed to water at 0 kPa SMT, and in different SMT ranges up to 30 kPa. The results show large percentages of water held between 0 and one kPa and one and 5 kPa SMT. Low percentages of water were held in all media at SMT greater than 5 kPa. The percentages of water held by the bark, soil, and peat media between 5 and 30 kPa were 5.8%, 9.8%, and 9.8% respectively. Therefore, the time required to go from 5 to 30 kPa SMT was small because the volume of water available was small.

Another explanation may be that the duration of stress was not long enough to affect the metabolic processes involved in growth. Acevedo et al. (1) found that maize leaves showed reduced cell elongation at SMT as low as 20 kPa. They reported, however, that mild and short stress resulted in transitory, rapid growth after irrigation that made up for the reduced growth that occurred under stress conditions. They suggested the metabolic processes necessary for growth were not affected by the stress and that growth after watering was only the result of a postponed event. Growth of maize leaves was irreversibly reduced at SMT of 250–300 kPa.

Table 4 lists the results of grouping the treatments by water volume remaining in the pot prior to watering. The results show a clear trend of increased final height, fresh weight, dry weight, and flower number as the volume of water remaining in the pot at watering increased. After 4 weeks with this grouping there were no differences in height, because these height measurements were taken only one week after treatments were applied. Treatments containing more than 500 ml of water in the container at watering had increased final height, fresh weight, dry weight, and flower number compared to those treatments with less than 500 ml water. It seems from these data that under the greenhouse production watering ranges used, the total volume of water in the container at any given time may be of greater importance than the tension at which the water is held.

In Table 5, the total porosity, container capacity, and air spaces for each medium are predicted. The values were all calculated using the model equations in Fig. 1. The values for total porosity are analogous to the values for 0 kPa SMT given in Table 3 (Table 3 lists the measured value and Table 5 the predicted value). Although total porosity will not change for a given medium (at similar bulk density), the container capacity and air space are specific for a 16.5-cm azalea pot. These 2 parameters are affected by the height of the medium column. As container height increases, more water is drained due to gravity, and vice versa. A classic example of this relationship is the classroom exercise with a sponge described by Spomer (23). These data suggest that air space values cannot be accurately given for a medium without regard for specific container sizes, as reported previously (2, 4, 6, 7, 17, 21).

Results of this study indicate that container water content may be more significant than SMT in affecting plant growth under greenhouse production conditions. The tensions at which plants should be watered may vary, depending on the medium. The relationship between container size and air space indicates that the expression of physical property data with reference to specific container sizes may prove to be a useful tool in determining air and moisture relationships of container-grown plants.

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Cauliflower, Broccoli, and Brussels Sprouts Responses to Concentrated Superphosphate and Potassium Chloride Fertilization

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Abstract. **Cauliflower (*Brassica oleracea* var. *botrytis* L. 'Imperial 10-6'), broccoli (*Brassica oleracea* var. *italica* Plenck 'El Centro'), and brussels sprouts (*Brassica oleracea* var. *gemmifera* Zenk. 'Jade Cross') were grown at 0, 84, 336, and 1344 kg of concentrated superphosphate (CSP) (0, 17.5, 70, and 280 kg P) and 0, 67, 268, and 1072 kg of potassium chloride (KC1) (0, 35, 140, 560 kg K) fertilizers per hectare, per application in a long-term plant nutrition experiment. Increasing the rate of CSP increased the concentrations of P, Ca and Mg but decreased K and Zn in leaf blades at midseason. Increasing the rate of KC1 increased the concentrations of K and Zn but decreased Ca and Mg in leaf blades. Increasing the rates of CSP and KC1 hastened maturity and increased yields of cauliflower and broccoli in harvest sequences, whereas brussels sprouts were less responsive to CSP or KC1 at one harvest. High rates of CSP without KC1 reduced the yield of cauliflower compared to the lower rates. Increasing the rate of KC1 increased the incidence of hollow stem, a quality defect, in cauliflower and broccoli. Best production of uniform maturity and yield was obtained with a combination of the CSP at 336 $kg \cdot ha^{-1}$ and KC1 at 268 to 1072 $kg \cdot ha^{-1}$ per application in a long-term rotation.**

Uniformity in growth, development, and maturation among cauliflower, broccoli, and brussels sprouts plants is necessary in order to obtain optimum yield and quality from a high percentage of the plants at a single harvest date. Genetics of the plants (1, 3, 5, 6), the environment, and cultural practices including fertilization (2, 4, 7, 8, 11, 12, 14) may affect the uniformity among plants and the yield and quality of these crops at harvest. Many soils used for production of vegetables have accumulated high levels of available soil P and medium to high levels of soil K from previous applications of P and K fertilizers (9).

The objectives of this long-term, plant nutrition experiment, initiated in 1963, were to determine the relationships of applied CSP and KC1 to a) available soil P and K as measured by soil tests, b) uptake of P and K and other elements by the plants as measured by tissue analysis, c) responses of crops to CSP and KC1 as measured by vegetative growth, development, and maturation of the plants during the growing season, and d) yield and quality of the portions of the plants used for human consumption (10). The objectives of this part of the experiment were to determine the effects of CSP and KC1 on the concentrations of elements in the leaves and the maturity, yield, and quality of cauliflower, broccoli, and brussels sprouts.

Materials and Methods

A factorial combination of CSP at 0, 84, 336, and 1344 kg (0, 17.5, 70, and 280 kg $P \cdot ha^{-1}$ and KC1 at 0, 67, 268, and 1072 kg (0, 35, 140, and 560 kg $K \cdot ha^{-1}$) were applied as a preplant broadcast and mixed in the soil each year, except 1966, from 1963 to 1968 to a Honeoye fine, sandy loam (Glosoboric Hapludalf, fine loamy, mixed, mesic) (10). The GSP and KC1

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