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Growth, Physiological Processes and Yield of Tomatoes Grown in Different Root Zone Volumes Using Sand Culture

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ABSTRAK

Pengaruh beberapa isipadu zon akar (2000, 4000 dan 6000 cm³) terhadap pertumbuhan, kaitan air, respons stomata, kadar fotosintesis, pemakanan tanaman dan hasil di dalam kultur pasir. Pokok disampel untuk analisa pertumbuhan setiap 2 minggu selama 56 hari. Perkembangan daun, jisim kering batang dan akar dikurangkan dengan isipadu zon akar 2000 cm³ dan 4000 cm³. Hasil basah buah juga dikurangkan apabila tanaman di tanam di dalam isipadu zon akar yang rendah. Walaubagaimanapun, isipadu zon akar tidak menunjukkan pengaruh yang signifikan terhadap peratus jisim kering buah dan kandungan bahan terlarut. Pengurangan pertumbuhan dan perkembangan tanaman apabila pokok ditanam didalam isipadu zon akar 4000 cm³ dan kurang, dihubungkaitkan dengan pengurangan di dalam potensi air, kadar fotosintesis dan pengambilan nutrien.

ABSTRACT

*The effects of different root zone volumes (2000, 4000 and 6000 cm³) on growth, water relations, stomatal responses, photosynthetic rate, mineral nutrition and yield of tomatoes (*Lycopersicon esculentum *Mill.) grown in sand culture were investigated . The plants were sampled for growth analysis fortnightly for a 56-day period. Leaf growth, stem and root dry weights were significanlty reduced with root zone volumes of 2000 and 4000 cm³. Total fruit fresh weight was reduced when plants were grown with decreasing root zone volumes. Root zone volumes, however, did not produce a significant effect on percentage of fruit dry matter and total soluble solids. The reduction in plant growth and development was associated with reduction in water potential, photosynthetic rate and mineral nutrient uptake when plants were grown in root zone volumes of 4000 cm³ or less.*

INTRODUCTION

Conventional vegetable cultivation in the tropics is always limited, mainly due to the presence of soil-borne diseases and nematodes. Recently, there has been increasing interest in the use of soilless substrate technique for producing horticultural crops, particularly in Malaysia. The Nutrient Film Technique (NFT)-trough system has been developed and proven to be feasible for producing horticultural crops (Lim, 1990). However, one of the disadvantages of the NFT-trough system still remains, namely the recirculating nutrient solution needs to be managed carefully to prevent imbalance of the various nutrients. Furthermore, in recirculating nutrient systems, diseases could easily be spread (Lim, 1986).

To overcome the above problems, research was started using a non-recirculating system utilizing organic and inorganic substrates. Ismail *et al.* (1993) reported that sand was suitable for the production of tomatoes, but its disadvantage was its weight that was very heavy compared with sawdust. Sawdust would be more utilized if the risk of some species of wood producing inhibitory effects could be overcome.

One of the main factors that control plant growth and development of plants grown using aggregate soilless culture is the root zone volume. Reducing root zone volume minimises the cost of production, especially when utilizing sand. Carmi and Heur (1981) reported that reducing soil volume was beneficial in producing dwarf plants especially during periods of low radiation.

For tomatoes, Raja Harun and Muhamad (1992) found no significant effect of different volumes of coconut potting mix used for the production of tomatoes. Prasad and Maher (1992) showed a similar response where varying the volume of substrate from 1.25 *l* to 14 *l* of coarse peat and up to 5 *l* for rockwool did not significantly affect yield of tomatoes in a recirculating system. Ruff *et al.* (1987) suggested that for a given growing area, a culture system using small containers would be more efficient in producing tomatoes of a given weight and size of plant than using large containers based on their data from soil volumes of 450 cm^3 and 13500 cm^3. Reduced root volume which causes root restriction will, however, result in the detrimental effect of reducing both the morphological and physiological processes in tomato plants (Peterson *et al.*, 1991).

The present study investigated the possibility of reducing sand volume for the production of tomatoes with the main objective of increasing productivity per unit area. The parameters investigated were changes in growth, stomatal response, photosynthetic rate and mineral nutrition; the possible role of water in affecting plant growth and development; and harvest index and biomass production were also examined.

MATERIALS AND METHODS

Tomato seeds, (*Lycopersicon esculentum* Mill. cv. MT1) supplied by the Malaysian Agricultural Research and Development Institute (MARDI), were sown in Jiffy pots. Four weeks after sowing, the seedlings were transferred to sand culture. To ensure root establishment, plants were irrigated with tap water for 4 days. The experiment was conducted in a glasshouse at the Hydroponic Unit, Universiti Pertanian Malaysia, Serdang, Selangor, Malaysia. Daily air temperatures ranged from 24°C to 36°C and relative humidity between 42% and 84%. A total of 144 plants was initially grown in three different sand volumes, namely 2000, 4000 and 6000 cm^3, in polybags with holes to allow drainage. The experiment was conducted in a completely randomized design with six replications. Harvests of plant material were made on days 14, 28, 42 and 56 to estimate net assimilation rate (NAR), harvest index (HI) and root:shoot ratio. The calculation of NAR and HI followed those of Hunt (1982). For each harvest, leaf area was determined using an automatic leaf area meter (Delta T Device, Cambridge, UK). Plants were separated into leaves, stems and roots and oven-dried for 72 h at 65°C prior to weighing. The nutrient concentration of 2.5 mS cm^{-1} of Cooper Formulation (Cooper, 1979) and a pH of 5.5-6.0 was supplied to the plants via drip emitters. Fertigation was carried out four times daily during the day at intervals of 3 h/per cycle. Each fertigation cycle of 10 min supplied adequate nutrients and water. Once a week, the substrate was flushed with tap water supplied through an emitter to avoid excessive accumulation of salts in the substrate. Using this technique, we did not observe any toxicity symptoms throughout the growth period.

Young, fully expanded leaves (3rd to 6th leaf from top of canopy) were sampled for leaf water potential determinations using a pressure chamber (Soil Moisture Eqpt. Corp. U.S.A). The stomatal resistance was measured with an automatic porometer (MK3, Delta T Device, Cambridge, UK). Measurement of the net photosynthetic rate for intact attached leaves was made using an infra red gas analyser (LCA-2 ADC Hoddesdon, UK).

Nutrient analysis of plant parts was carried out on plants sampled on days 14 and 42 following the procedure outlined by Husni *et al.* (1991). Nitrogen (N), Phosphorus (P), and Potassium (K) contents were determined using Technicon Auto-analyser II, while Ca was determined by atomic absorption spectrophotometer.

Flower number was recorded weekly and percentage of fruit set determined. Harvesting of fruits was carried out when they changed from yellow to red. The numbers of normal and abnormal fruits were recorded. Total fruit weight of normal fruits was obtained. Individual fruit diameters were recorded using a Vernier caliper. Five fruits per plant were sampled for total soluble solids, measured using a hand refractometer, and for percentage dry weight.

RESULTS

Plant Vegetative Growth

Over 56 days, plant height did not differ significantly ($P>0.05$) between treatments. Stem diameter was significantly reduced ($P<0.05$) in the 2000 cm^3 treatment. No significant difference was observed for stem diameter between the 4000 cm^3 and 6000 cm^3 treatments *(Fig 1.)*. By day 56, leaf area and dry weight were significantly

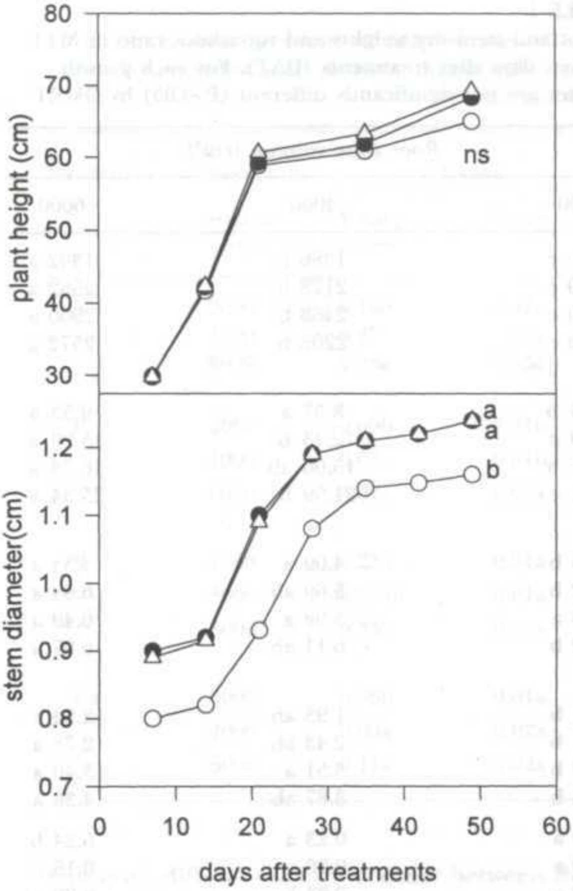

Fig. 1: Plant height and stem diameter as influenced by different root zone volumes. ○=2000 cm³ ●=4000cm³ and △=6000cm³. Means separation by DMRT, P=5%

lower (P<0.05) with decreasing volumes of sand (Table 1), being 15% lower in the 2000 cm³ treatment and 30% lower in the 4000 cm³ treatment than for plants grown in 6000 cm³ of sand. Similar reductions were observed for root and stem dry weights. The results for root:shoot ratio between plants grown in diferent root zone volumes were inconsistent and in general indicate that there was a shift of dry matter deposition from leaves to the stem with decreasing root zone volume.

Plant Growth Analysis

Table 2 shows root zone volumes had little or no effect on net assimilation rate and harvest index. The results for sampling at interval 2-4 weeks for the net assimilation rate was significantly greater for the 2000 cm³ treatment, but this difference between treatments diminished with time.

Water Relations, Stomatal Resistance (Rs) and Photosynthetic Rate (Pn)

The leaf water potential declined progressively with time. This was particularly marked for the lower root zone volume treatments *(Fig. 2)*, the greatest drop from -0.29 MPa at 7 days to 0.8 MPa at 56 days occurred in the smallest root zone volume.

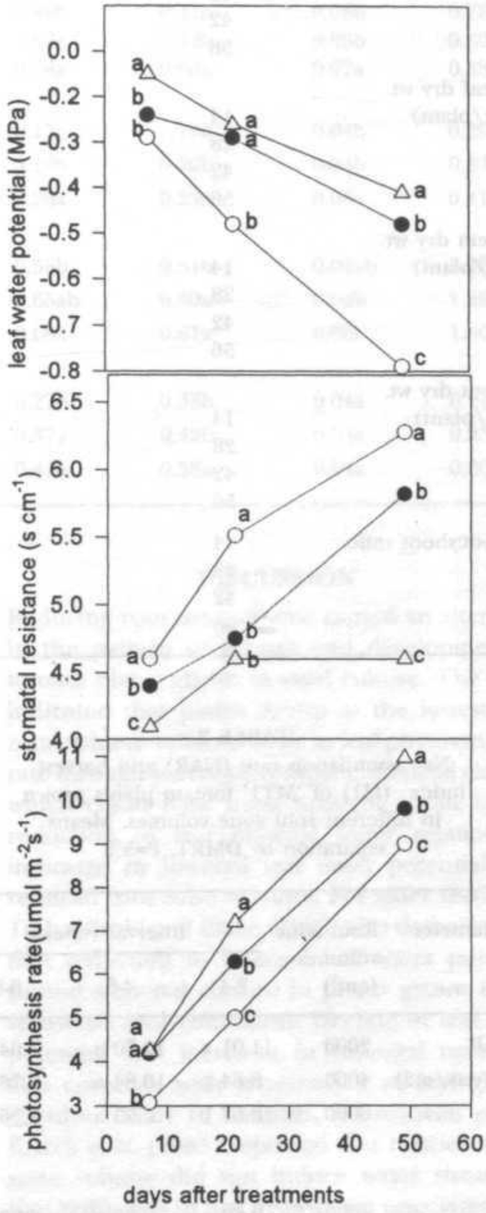

Fig. 2: Leaf water potential, stomatal resistance and photosynthetic rate as influenced by root zone volumes. ○=2000cm³; ●=4000cm³ and △=6000cm³. Means separation by DMRT, P=5%

TABLE 1
Influence of root zone volume on leaf area, leaf, root and stem dry weights and root:shoot ratio in MT1 tomato. Data are means of 6 replications for a given days after treatments (DAT). For each growth parameter, means within a row followed by same letter are not significantly different (P>0.05) by DMRT

Parameter	Days after treatment	Root zone volume (cm^3)		
		2000	4000	6000
Leaf area (cm^2)	14	958 c	1286 b	1392 a
	28	1400 c	2178 b	2562 a
	42	2000 c	2468 b	2900 a
	56	1796 c	2206 b	2572 a
Leaf dry wt. (g/plant)	14	6.74 b	8.57 a	9.53 a
	28	9.69 c	12.43 b	15.20 a
	42	12.81 b	15.06 ab	16.73 a
	56	17.61 c	21.59 b	25.34 a
Stem dry wt (g/plant)	14	3.05 b	4.09 a	4.34 a
	28	4.12 b	5.69 ab	6.04 a
	42	5.13 a	5.98 a	6.49 a
	56	6.12 b	6.11 ab	6.87 a
Root dry wt. (g/plant)	14	1.31 b	1.93 ab	2.34 a
	28	1.81 b	2.43 ab	2.78 a
	42	2.63 b	3.51 a	3.40 a
	56	3.04 b	3.87 ab	4.38 a
Root:shoot ratio	14	0.19 a	0.23 a	0.24 b
	28	0.19 a	0.20 a	0.18 a
	42	0.20 a	0.23 b	0.20 a
	56	0.17 a	0.18 a	0.17 a

TABLE 2
Net assimilation rate (NAR) and harvest index (H1) of 'MT1' tomato plants grown in different root zone volumes. Means separation by DMRT, P=5%

Parameter	Root zone volumes (cm^3)	Interval (weeks)		
		2-4	4-6	6-8
NAR (g/day/m2)	2000	11.01 a	12.70 a	7.64 a
	4000	8.84 b	10.84 a	7.78 a
	6000	8.67 b	9.55 a	7.26 a
HI	2000	0.60 a	0.76 a	0.80 a
	4000	0.61 a	0.75 a	0.79 a
	6000	0.62 a	0.75 a	0.83 a

The difference in Rs and Pn between the 4000 cm^3 and 6000 cm^3 treatments was not significant throughout the observation period. For the smallest root zone volume treatment, Rs was highest and Pn lowest throughout the observation period, the Pn at Day 49 being 30% less than for plants grown in 6000 cm^3 soil.

Mineral Nutrition

Nutrient content in different plant parts at Day 14 and 42 for the three treatments are shown in Table 3. N content in young leaves on both sampling dates was significantly lower in plants grown in 2000 cm^3 sand. In contrast, the different root zone volumes had no appreciable effect on N content in the roots and fruits.

Reducing root zone volume to 4000 cm^3 did not significantly affect P content in young leaves sampled at Day 14, but caused a remarkable decline of P content by Day 42.

TABLE 3

Nutrient content (g/plant) of different parts of tomato plants grown for 14 and 42 days in different root zone volumes. For each nutrient, means within a column followed by the same letter are not significantly different (P>0.05) by DMRT

Nutrient	Root zone volume (cm3)	14 days Young leaves	14 days Roots	42 days Young leaves	42 days Mature leaves	42 days Roots	42 days Fruits
N	2000	0.16b	0.02a	0.46b	0.41c	0.06b	0.78a
	4000	0.27a	0.02a	0.63a	0.52b	0.06b	0.80a
	6000	0.28a	0.03a	0.76a	0.60a	0.07a	0.88a
P	2000	0.05b	0.01b	0.17c	0.19b	0.04b	0.29b
	4000	0.07a	0.01b	0.19b	0.20b	0.04b	0.33b
	6000	0.07a	0.03a	0.26a	0.23a	0.06a	0.41a
K	2000	0.23b	0.01a	0.58b	0.51b	0.05ab	1.12b
	4000	0.21ab	0.01a	0.65ab	0.60a	0.04b	1.28ab
	6000	0.33a	0.02a	0.68a	0.61a	0.06a	1.60a
Ca	2000	0.06b	0.01a	0.27b	0.38b	0.04a	0.21b
	4000	0.09a	0.02a	0.37a	0.42b	0.04a	0.23ab
	6000	0.11a	0.02a	0.41a	0.58a	0.04a	0.30a

However, differences in P content between the 2000 cm^3 and 4000 cm^3 treatments were not significant for root, mature leaves and fruit. A similar reduction in K content was found in young leaves of plants grown in the smallest root zone volume. There was also a 40% reduction in Ca content in young leaves in the 2000 cm^3 treatment compared with plants grown in 6000 cm^3 sand; but for Ca content in the root, there was a negligible difference.

Yield

Table 4 shows the effects of the different root zone volumes on fruit production at final harvest. The total fruit fresh weight was 30% and 18% greater in the 6000 cm^3 treatment than in the 2000 cm^3 and 4000 cm^3 treatments, respectively. Reduction in fruit fresh weight in the 2000 cm^3 treatment was associated with lower fruit number caused by reduction in percentage fruit set, and smaller diameter fruits. Harvest index measured on a dry weight basis was not significantly different between treatments (Table 2), nor did root zone volumes affect percentage dry matter and total soluble solids in the fruits.

DISCUSSION

Reducing root zone volume caused an alteration in the pattern of growth and development of tomato plants grown in sand culture. The study indicated that plants grown at the lowest root zone volume suffered stress in leaf photosynthetic rate through partial or complete stomatal closure, which could have been brought about by the reduction in leaf internal water relations as indicated by lowered leaf water potential with reduced root zone volumes. For alder seedlings, Tschaplinski and Blake (1985) also demonstrated that reduction in internal leaf water potential caused stomatal closure in plants grown under restricted root conditions. Decline in leaf water potential and increases in stomatal resistance also correlate with termination of leaf growth (Shulze, 1986) In contrast, for soybean plants, Krizek *et al.* (1985) reported that restricted root zone volume did not induce water stress and that reduction in leaf growth was associated with other physiological mechanisms. In the present study, although reduction in leaf water potential for the lowest root zone volume did not exceed -1.0 MPa, we suggest that this level may have

TABLE 4
Influence of different root zone volumes on fruit production. Means separation by DMRT, 5%

	Days after treatments	Root zone volume (cm3)		
		2000	4000	6000
Fruit number (unit/plant)	-	15.0 b	19.0 a	19.0 a
% fruit set	-	68.3 b	84.0 a	86.5 a
% normal fruit	-	85.1 a	85.7 a	84.3 a
Fruit diameter (cm)	-	3.43 b	3.55 ab	3.83 a
Fruit fresh wt (g/plant)	28	84.72 b	152.25 a	156.30 a
	42	398.15 a	435.92 a	494.19 a
	56	407.24 b	454.98 b	616.04 a
	Total	811.11 c	1043.15 b	1266.53 a
% fruit dry matter	-	8.42 a	7.92 a	7.12 a
Total soluble solids (% Brix)	-	5.67 a	6.33 a	5.67 a

already affected leaf growth. This is consistent with the suggestion that the primary effects of water stress (slight to moderate) are reduced leaf growth either in the cell extention phase or in both the cell division and cell extention phases of leaf growth (Begg and Turner, 1976).

The other mechanisms brought into play by restricted root growth include a combination of reduced water absorption, reduced hormone synthesis and an increased allocation of assimilates translocated to the root. The latter mechanism may be applicable in the present sudy, where root:shoot ratio tended to be greater with reduction in root zone volume from 6000 to 4000 cm^3. The involvement of gibberellin and cytokinin has been demonstrated by Richards and Rowe (1977) and Carmi *et al.* (1983). Peterson *et al.* (1991) demonstrated a slight increase in ethylene production when adventitious rooting was initiated, but that overall ethylene production rates did not differ significantly in tomato plants. Similarly, Thomas (1993) ruled out the only possible regulation of ethylene production that caused the reduction in plant size and alterations in allometry of carrots plants, as being due to both nutrient depletion and lack of aeration or restricted recirculated nutrient solution. No attempt was made in the present study to examine the role of hormonal changes due to reduced root zone volume.

The fact that reduced root zone volume did not decrease the harvest index agrees with that observed by Ruff *et al.* (1987), and indicates that tomato plants can adjust their fruit production per plant according to pressures on the root system, a similar situation to those grown in high planting densities. Furthermore, the shift of dry matter allocation to the root and probably also to the stem, contributes toward this effect and may explain the lack of significant difference in the net assimilation ratio.

The lower concentration of nutrient elements in the plant with reducing root zone volumes may reflect a physiological disruption that limits nutrient uptake, but we have no data to support this.

Reducing root volume can be a practical means of reducing cost of production of tomatoes using soilless media. However, this study shows that yield was reduced by 34% at the lowest root zone volume (2000 cm^3). Further studies need to be carried out to minimize or eliminate the reduction in yield by adjusting aspects of irrigation and nutrition requirements.

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