completely free of injury or severely injured externally and/or internally, also failed to indicate any clear relationship between any of these parameters and CO_2 injury (data not shown).

An examination of the 25 lots of CO_2-treated 'Golden Delicious' apples obtained from Washington State suggests that these fruits were less susceptible to CO_2 injury. External injury averaged 1.5% (range: 0–13.5% and internal injury 0.1% (range: 0–1.4%). The incidence of external and internal CO_2 injury was, as in B.C. apples, not related to size, skin color, soluble solids, titratable acidity, firmness, and mineral (N, K, Ca, Mn, Mg, and Zn) content of the fruits (data not shown).

The reason why B.C. 'Golden Delicious' behave differently from those grown in Washington remains unknown. Analyses of the Washington and B.C. apples revealed little difference in fruit firmness, size, titratable acidity, and Ca content but Washington fruits were less green and were lower in N, Mn, and Zn and higher in soluble solids, in K, and Mg (Table 5). The fruit color and soluble solids data would suggest that the Washington fruits were of somewhat better quality but whether any of these differences could account for the disparity in CO_2 response is still open to question. High tree vigor with a light crop, immature fruits, spring frost damage, large fruit size, and excessive levels of CO_2 and duration of the CO_2 treatment have been suggested by R. D. Bartram (personal communication, 1977) to be factors associated with CO_2 injury. Meheriuk (4) observed that CO_2 injury to the skin was likely to be more severe in the earlier harvested fruit whereas internal injury tended to be more extensive in more mature fruit. Recently, we showed that moisture on fruit surfaces resulted in a high incidence of CO_2-associated skin injury (3). A similar but less direct observation was also noted by Bartram (personal communication).

In conclusion, CO_2 treatment before CA storage of 'Golden Delicious' apples in Washington State appears to be a commercially successful innovation. It does not presently appear promising for B.C. because the levels of CO_2 injury are excessive and results to date show the firmness retention response to be very marginal.

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Early Root Growth of Carrots in Organic Soil[1]

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Abstract. **Early root growth of carrots (*Daucus carota* L.) was studied in specially constructed pots containing organic soil under controlled environments at 16°, 20°, 24°, and 28°C. Carrot tops produced greater amounts of bio-mass on a fresh or dry weight basis than did roots, whereas taproots demonstrated faster rates of linear growth than did the tops throughout the 24-day sampling period at all temperatures. The optimum range of temperatures for carrot root growth was 20-24°C. Taproots reached the potential length for market-acceptable storage roots (15.2 cm) between 12 and 16 days after planting at 20°, 24°, and 28°C and after 20 days at 16°C. Average taproot lengths after 24 days at 16°, 20°, 24°, and 28°C were 23.6, 38.5, 35.6, and 16.7 cm, respectively. Secondary roots had developed by the 8th day and tertiary roots by the 20th day. Tertiary roots were confined to the upper 5 cm of the root system at this early date.**

The quality of bunched and topped carrots produced for fresh market depends heavily upon the configuration of the storage root. Grading standards as well as consumer acceptance have dictated criteria for root length, diameter, and the variability of these factors, as well as freedom from defects such as crooking and forking (4). The anatomical changes during development of the carrot have been described by Esau (2) and Havis (3). Recent reports by Phan and Hsu (5) and Slinger (6) are in good agreement with earlier descriptions of root growth in carrots. However, none of these workers studied in detail the early stages of taproot growth.

Reported effects of temperature and moisture on carrot root development are mostly a result of field observations and impressions (7). Barnes (1) has provided some experimental work which supports many of these observations. However, he investigated carrot root development after secondary thickening of the storage root had begun.

As part of an in-depth study of physical and biological factors affecting carrot root configuration and disorders, we report herein results describing the early stages of root growth of fresh market type carrots under controlled environment conditions.

Materials and Methods

Early carrot root growth was studied using specially constructed pots made of 10.2 cm inside diam polyvinyl chloride pipe. Sections of pipe 38 cm long were cut longitudinally into halves and rejoined with weatherproof tape. To facilitate removal of the soil and roots, the tape was removed and pots split apart for examination. Pots were filled within 2 cm of the top with an organic soil (Everglades mucky-peat) which had been steamed for 6 hr and sieved through a 0.64 cm mesh screen. The soil in each pot was packed to provide a medium soil compaction. A penetrometer (Model CL-700, Soil Test, Inc.) was used to measure soil compaction and each pot was

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packed to provide a uniform compaction reading of 1.56 kg/ cm^2 unconfined strength. Seeds of 'Dominator' and F_1 fresh-market hybrid carrot, were germinated at 24°C in Petri dishes on filter paper moistened with distilled water. After 3 days at 24° the radicles had grown to about the length of the seed coat and the seeds were ready for planting. Five germinated seeds were evenly spaced on the packed soil surface in each pot and then covered with an additional 1 cm of soil. The soil covering the seeds was pressed lightly and 50 ml of tap water applied. Six pots were selected at random for each treatment and placed in environators at constant temp of 16°, 20°, 24°, and 28° with a 12-hr day-length. The tops of the pots were placed 28 cm below six 25-watt (F25 T12 25 W) cool-white fluorescent tubes supplemented by four 15-watt incandescent bulbs. Fifty ml of tap water was added daily to each pot. Because water in pots held at 24° and 28° evaporated more rapidly, they received 100 ml of water daily during the last 6 days of the experiment.

Three days after planting, one pot was removed from each environator and thereafter at 2-day intervals. Soil was carefully washed from the roots of the 5 plants from each pot with a fine stream of water under moderate pressure to avoid breaking the tap and lateral roots. Taproot length, top ht, and total fresh and dry wt (dried at 120°C for 24 hr) were measured. Taproot length measurements were made from the cotyledonary node to the root tip. Top ht measurements were made from the tip of the longest expanded cotyledon to the cotyledonary node. After expansion of the first true leaf, top ht measurements were made from the tip of the longest true leaf to the cotyledonary node.

In a second, but similar experiment, growth data were taken at 4-day intervals beginning on the 4th day after seeding and continuing for a period of 24 days after seeding. In addition to root and top measurements, diagramatic drawings were made of root configurations and plant growth at 24°C for each 4-day interval from selected plants which conformed most closely to mean values obtained.

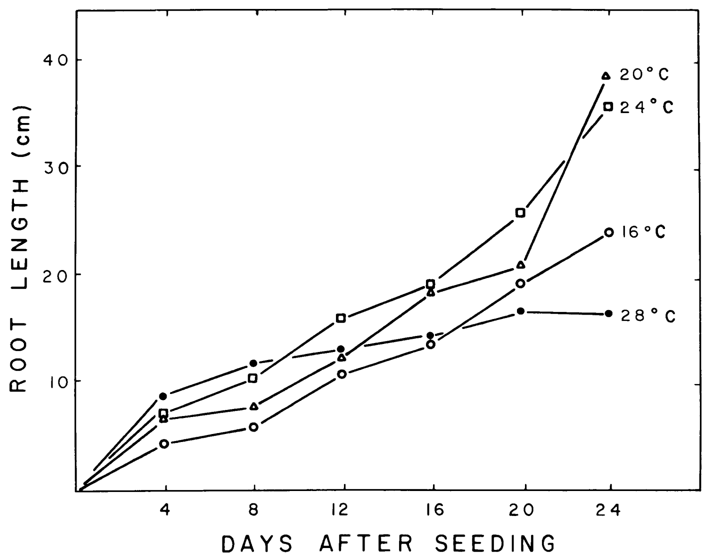

Fig. 1. Early linear growth of carrot roots from plants grown in an organic soil under controlled environmental conditions with 12-hr daylength at 16, 20, 24, and 28°C.

(dry wt) at each temp than did roots during the first 24 days of growth (Table 1). Plant growth as measured by total plant fresh wt was greatest at 20°, and was significantly greater than at other temp. However, the total dry wt at 20° was not significantly greater than the dry wt at 24° (Table 1).

Carrot tops (cotyledons and true leaves) grew in length at an average rate per day of 1.2 mm at 16°C, 2.1 mm at 28°, 3.4 mm at 20°, and 4.3 mm at 24°. Carrot taproots grew in length at an average rate per day of 7.1 mm at 28°, 9.8 mm at 16°, 14.8 mm at 24°, and 16.0 mm at 20°.

Results

Under the conditions of these experiments, a striking early and rapid growth of carrot taproots was observed at all temp used. Moreover, taproots continued their rapid increase in length at constant temp of 16°, 20°, and 24°C throughout the 24-day sampling period. Only at 28° was a decrease in rate of growth measured and it occurred between the 20th and 24th day of the experiment. Several plants growing at 20° and 24° attained a length of 43 cm which was the maximum length possible in the system employed. The maximum average taproot length at 24 days was 38.5 cm and this occurred at 20° (Fig. 1).

There were no significant differences between average carrot root lengths at 20°C (38.5 cm) and 24° (35.6 cm, LSD 5% = 5.6) treatments. Root lengths at 16° (23.6 cm) were significantly shorter than at 20° and 24° and significantly longer than at 28° (16.7 cm).

Diagramatic drawings of leaf and root growth of representative plants grown at 24°C (Fig. 2) illustrate typical early taproot growth and root systems observed in these experiments. Secondary root growth occurred by the 8th day and tertiary roots were observed by the 20th day at 24°. However, tertiary roots were confined to the upper 5 cm of the root system. Top growth was somewhat slower than root growth during this early period. The first true leaf appeared on the 12th day. The 2nd and sometimes 3rd leaf were observed to expand by the 20th day at 24°.

Although the taproots grew more rapidly in length than the tops (Fig. 1 and 3), tops generally produced greater bio-mass

Discussion

The results of this study provide new information on 3 important aspects of early carrot taproot growth. In terms of physical length, young carrot taproots grew faster than did the tops, whereas at optimum growth temp, tops generally produced greater amounts of bio-mass on a fresh or dry wt basis than did roots (Table 1). The exception being the fresh wt of roots grown at 16°C which were greater than the top wt. Phan and Hsu (5) reported that the first organs of carrots to grow actively were the leaves which reached a length of 13-18 cm within 2 weeks. Moreover, they found that taproot length began to increase only after the leaves reached this height. Additionally, they reported that taproots remained "thin"

Table 1. Bio-mass of tops and roots of carrot seedlings after 24 days growth at a constant temp and 12-hr daylength under controlled environmental conditions. Values are averages of 5 plants.

Temp (oC)	Avg fresh wt (mg)/plant			Avg dry wt (mg)/plant		
	Top	Root	Total	Top	Root	Total
16	44.7	81.6	126.3	3.1	2.9	6.0
20	219.0	215.2	434.2	19.2	7.1	26.3
24	281.3	110.3	391.6	18.3	4.0	22.3
28	54.9	39.2	94.1	3.9	1.4	5.3
LSD 5%			33.5			5.8

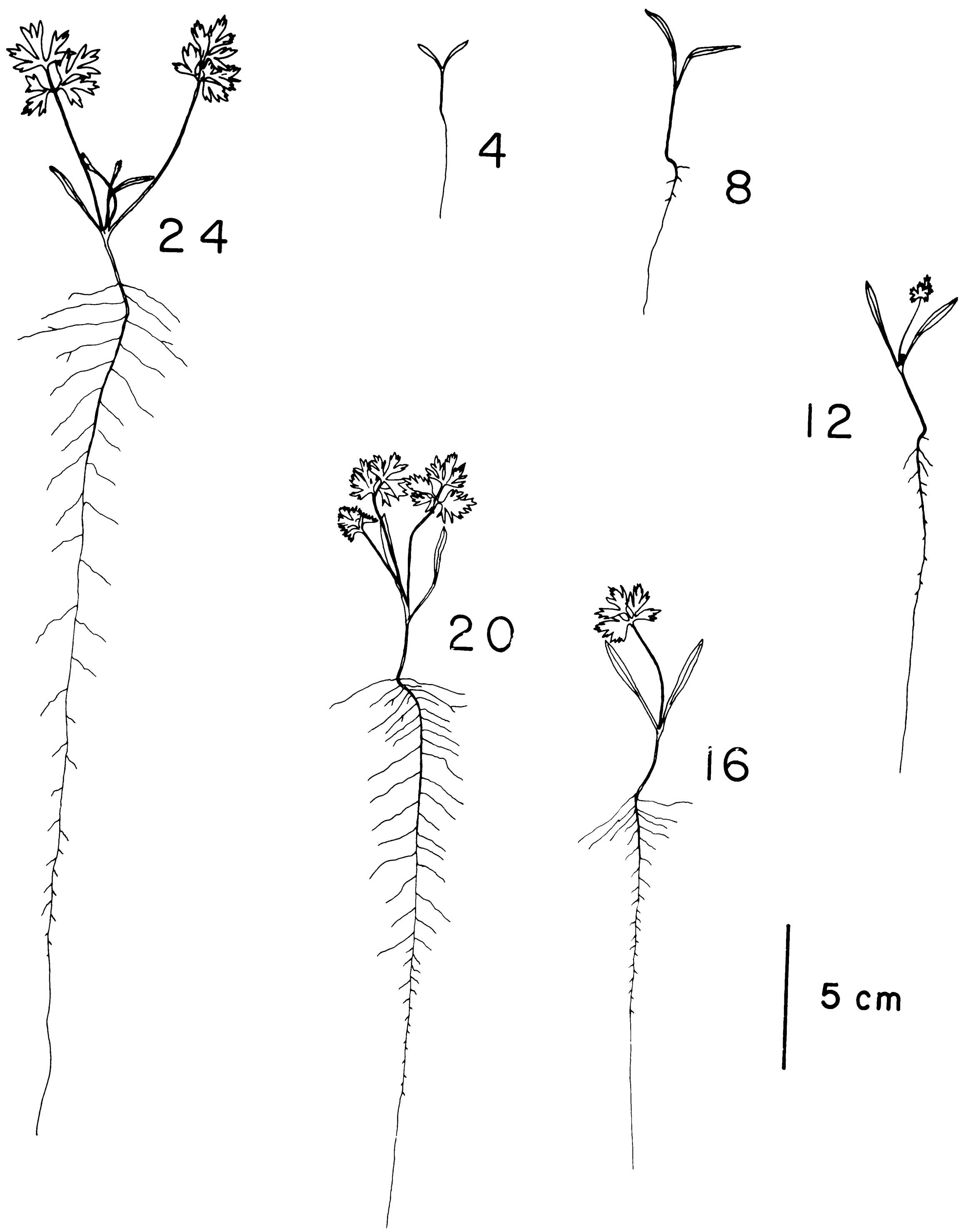

Fig. 2. Early growth of carrot top and root systems at 24°C in an organic soil under controlled environmental conditions with 12-hr daylength. Numbers refer to days after seeding. Diagramatic drawings are of plants conforming most closely to mean value obtained (see Table 1).

for another month, with both leaves and taproots reaching a maximum length of 26-39 cm. Slinger (6) supported their observations on carrot root development. In contrast, we found that in organic soil taproots of fresh market carrots grew actively in length from the time of germination and that their rate of growth continued until some taproots reached a length of 43 cm at 24 days. This was the maximum length we were able to measure in our experimental system. The difference in top and root growth we found may have been partly due to Phan and Hsu (5) using a different cultivar ('Imperator 11') and other differences in growing conditions.

From our study in organic soil, we conclude that early root growth was influenced by temp and that the optimum range for carrot taproot elongation was 20-24°C. This is in

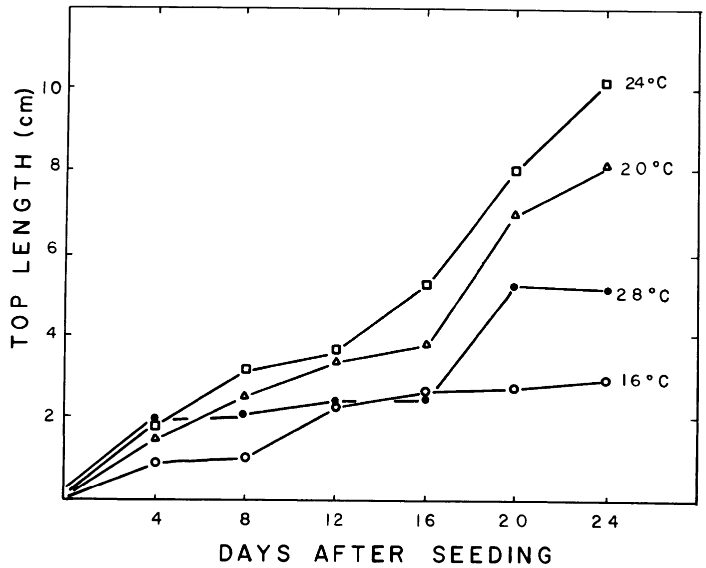

Fig. 3. Early linear growth of carrot tops from plants grown in an organic soil under controlled environmental conditions with 12-hr daylength at 16, 20, 24, and 28°C.

good agreement with the results of Barnes (1) who found that the size and shape of mature carrot storage roots were more typical in terms of shape and length for the cultivar he employed when they were grown at 16-22°. At temp higher than 22°, roots tended to be shorter than normal and at temp lower than 16° roots were longer than normal (1). We found the roots to be longest after 24 days when grown at 20°. However, the root length was longer at 20° than at 24° because of a rapid growth rate during the last 4 days (Fig. 1).

Of greater significance to carrot market quality were our observations of the striking rapid early growth of the carrot taproot (Fig. 1, 3). The carrot storage root develops from a secondary thickening of the hypocotyl and taproot (2, 3); thus, in organic soil at optimum temp, the potential for acceptable storage root length can be reached within 12-16 days of seeding. Under the conditions of our experiments, taproots grew rapidly with little secondary and tertiary root development and no visible secondary thickening. These observations do not agree with early root growth reported by Esau (2) who also worked with a market-type carrot, ('Imperator'). However, Esau did not emphasize early root growth in her study and the plants she used were germinated in wet moss rather than in soil. These facts could explain the differences in results obtained.

The U. S. grading standards for fresh market carrot root length require a minimum length of 15.2 cm. The results of this study using controlled environments showed that in an organic soil, taproots are able to reach this length between 12 and 16 days after seeding at optimum growth temp. This should correspond to 15 to 18 days after planting under normal field conditions. Within 24 days, taproots grown at all temp employed in this study had exceeded 16 cm in length. Many physical and biological factors which cause defects such as crooking, forking, and stubbed-off roots through the injury or interruption of normal taproot growth may act during this period of early growth. Thus, pest control or crop management tactics designed to prevent or reduce root disorders must be effective early in the life of the young carrot.

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