CARROT PRODUCTION
IN THE UNITED STATES

Agriculture Handbook No. 375
This handbook summarizes information on carrot production in the United States and is based on extensive research findings and grower experience. It is intended to give essential information for growers, seedsmen, processors, extension personnel, and others interested in the production of this crop.

Mention of a pesticide in this publication does not constitute a recommendation or endorsement by the U.S. Department of Agriculture. Registrations of pesticides may change as new information on uses and residues becomes available.

For data on pesticide dosages, tolerances, minimum days from last application to harvest or feeding, and similar information, refer to the following U.S. Department of Agriculture publications, which may be consulted in depository libraries:

- Chemical Control of Plant-Parasitic Nematodes (Agriculture Handbook 286)
- Suggested Guide for the Use of Insecticides to Control Insects Affecting Crops, Livestock, Households, Stored Products, Forests, and Forest Products (Agriculture Handbook 331)
- Suggested Guide for Weed Control (Agriculture Handbook 332)

Since chemical uses and specific dosages vary in different parts of the United States, consult State agencies for local recommendations.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Mention of a proprietary product in this publication does not constitute a guarantee or warranty by the U.S. Department of Agriculture over other products not mentioned.
# Contents

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic importance</td>
<td>1</td>
</tr>
<tr>
<td>Nutritional value</td>
<td>2</td>
</tr>
<tr>
<td>Taxonomy, origin, and domestication</td>
<td>2</td>
</tr>
<tr>
<td>Morphology</td>
<td>3</td>
</tr>
<tr>
<td>Breeding and genetics</td>
<td>4</td>
</tr>
<tr>
<td>Varieties</td>
<td>6</td>
</tr>
<tr>
<td>Seed production</td>
<td>7</td>
</tr>
<tr>
<td>Soil requirements</td>
<td>10</td>
</tr>
<tr>
<td>Climatic requirements</td>
<td>11</td>
</tr>
<tr>
<td>Effects of temperature on root development</td>
<td>11</td>
</tr>
<tr>
<td>Effects of environment on carotene content</td>
<td>11</td>
</tr>
<tr>
<td>Field management</td>
<td>12</td>
</tr>
<tr>
<td>Land preparation</td>
<td>12</td>
</tr>
<tr>
<td>Planting</td>
<td>12</td>
</tr>
<tr>
<td>Fertilization</td>
<td>14</td>
</tr>
<tr>
<td>Irrigation</td>
<td>15</td>
</tr>
<tr>
<td>Weed control</td>
<td>16</td>
</tr>
<tr>
<td>Rotations</td>
<td>16</td>
</tr>
<tr>
<td>Harvesting</td>
<td>17</td>
</tr>
<tr>
<td>Packing, storage, and processing</td>
<td>18</td>
</tr>
<tr>
<td>Diseases and their control</td>
<td>21</td>
</tr>
<tr>
<td>Field diseases</td>
<td>21</td>
</tr>
<tr>
<td>Cercospora blight</td>
<td>21</td>
</tr>
<tr>
<td>Alternaria blight</td>
<td>22</td>
</tr>
<tr>
<td>Root scab complex</td>
<td>23</td>
</tr>
<tr>
<td>Storage and transit diseases</td>
<td>23</td>
</tr>
<tr>
<td>Black rot</td>
<td>23</td>
</tr>
<tr>
<td>Bacterial soft rot</td>
<td>24</td>
</tr>
<tr>
<td>Watery soft rot or cottony soft rot</td>
<td>25</td>
</tr>
<tr>
<td>Diseases and their control—Continued</td>
<td></td>
</tr>
<tr>
<td>Storage and transit diseases—Continued</td>
<td></td>
</tr>
<tr>
<td>Gray-mold rot</td>
<td>26</td>
</tr>
<tr>
<td>Crater rot</td>
<td>26</td>
</tr>
<tr>
<td>Woolly soft rot</td>
<td>27</td>
</tr>
<tr>
<td>Fusarium dry rot</td>
<td>27</td>
</tr>
<tr>
<td>Licorice rot</td>
<td>28</td>
</tr>
<tr>
<td>Minor rots</td>
<td>29</td>
</tr>
<tr>
<td>Virus diseases</td>
<td>29</td>
</tr>
<tr>
<td>Aster yellows</td>
<td>29</td>
</tr>
<tr>
<td>Motley dwarf disease</td>
<td>30</td>
</tr>
<tr>
<td>Controlling field and storage diseases</td>
<td>31</td>
</tr>
<tr>
<td>Rotation</td>
<td>31</td>
</tr>
<tr>
<td>Planting location</td>
<td>31</td>
</tr>
<tr>
<td>Insecticides and fungicides</td>
<td>31</td>
</tr>
<tr>
<td>Harvesting procedures</td>
<td>31</td>
</tr>
<tr>
<td>Controlling storage temperature and relative humidity</td>
<td>31</td>
</tr>
<tr>
<td>Insects and their control</td>
<td>31</td>
</tr>
<tr>
<td>Wireworms</td>
<td>31</td>
</tr>
<tr>
<td>Carrot rust fly</td>
<td>32</td>
</tr>
<tr>
<td>Vegetable weevils</td>
<td>32</td>
</tr>
<tr>
<td>Carrot beetle</td>
<td>33</td>
</tr>
<tr>
<td>Western parsley caterpillar</td>
<td>33</td>
</tr>
<tr>
<td>Cutworms and armyworms</td>
<td>33</td>
</tr>
<tr>
<td>Six-spotted leafhopper</td>
<td>33</td>
</tr>
<tr>
<td>Loopers</td>
<td>34</td>
</tr>
<tr>
<td>May beetle</td>
<td>34</td>
</tr>
<tr>
<td>Occasional pests</td>
<td>34</td>
</tr>
<tr>
<td>Nematodes and their control</td>
<td>34</td>
</tr>
<tr>
<td>Root-knot nematode</td>
<td>34</td>
</tr>
<tr>
<td>Other nematodes</td>
<td>36</td>
</tr>
<tr>
<td>Selected references</td>
<td>36</td>
</tr>
</tbody>
</table>
CARROT PRODUCTION
IN THE UNITED STATES

By Thomas W. Whitaker, geneticist, Crops Research Division; Arden F. Sheer, professor of plant pathology, Cornell University; W. H. Lange, professor of entomology, University of California; Clark W. Nicklow, extension horticulturist, Michigan State University; and John D. Radewald, extension nematologist, University of California

ECONOMIC IMPORTANCE

Carrots are one of the principal vegetable crops in the United States. The average annual value of this commercial crop in the chief producing States during 1961–65 was $57,429,000. Carrots ranked ninth in value among the 28 principal vegetables grown commercially during this period and were preceded in descending order of value by potatoes, tomatoes, lettuce, snap beans, sweet corn, onions, cantaloup, and celery. This crop, like most other vegetables, increased in value in 1966 and 1967 to $69,994,000 and $69,678,000, respectively. Estimates are for fresh-market and processed carrots.

The average commercial carrot acreage in the important producing States during 1961–65 was 85,310 annually and in 1966 and 1967 was 83,855 and 83,785, respectively. Yields ranged from an average of 20,600 pounds per acre during 1961–65 to 21,600 in 1966 and 21,300 in 1967.

Total commercial production during 1961–65 in the major producing States averaged 844,250 tons, and when the minor producing States are included, it averaged 866,300 tons. Table 1 shows the important commercial carrot-producing States, harvesting seasons, and average annual crop value during 1961–65.

Table 1.—Important carrot-producing States, harvesting seasons, and average annual crop value during 1961–65

<table>
<thead>
<tr>
<th>Region and State</th>
<th>Harvesting season</th>
<th>Crop value 1,000 dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Atlantic:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connecticut</td>
<td>Early fall</td>
<td>651</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>do</td>
<td>971</td>
</tr>
<tr>
<td>New Jersey</td>
<td>Late summer</td>
<td>479</td>
</tr>
<tr>
<td>New York</td>
<td>Early fall</td>
<td>1,364</td>
</tr>
<tr>
<td>North Central:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illinois</td>
<td>Late summer</td>
<td>269</td>
</tr>
<tr>
<td>Michigan</td>
<td>Early fall</td>
<td>2,992</td>
</tr>
<tr>
<td>Minnesota</td>
<td>do</td>
<td>706</td>
</tr>
<tr>
<td>Ohio</td>
<td>Late summer</td>
<td>294</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>do</td>
<td>1,139</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Early fall</td>
<td>1,169</td>
</tr>
<tr>
<td>South Central, Texas</td>
<td>Winter</td>
<td>15,262</td>
</tr>
<tr>
<td></td>
<td>Early fall</td>
<td>4,204</td>
</tr>
<tr>
<td>Western:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arizona</td>
<td>Spring</td>
<td>2,250</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>7,479</td>
</tr>
<tr>
<td>California</td>
<td>Early summer</td>
<td>7,904</td>
</tr>
<tr>
<td></td>
<td>Late fall</td>
<td>7,917</td>
</tr>
<tr>
<td>Colorado</td>
<td>Early fall</td>
<td>1,507</td>
</tr>
<tr>
<td>New Mexico</td>
<td>Spring</td>
<td>2,63</td>
</tr>
<tr>
<td>Oregon</td>
<td>Early fall</td>
<td>804</td>
</tr>
<tr>
<td>Washington</td>
<td>do</td>
<td>966</td>
</tr>
<tr>
<td>Alaska</td>
<td></td>
<td>49</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>57,429</td>
</tr>
</tbody>
</table>

1 Winter = Jan.–Mar.; spring = Apr.–June; early summer = July 1–Aug. 15; late summer = Aug. 16–Sept. 30; early fall = Oct. 1–Nov. 15; late fall = Nov. 16–Dec. 31.
2 4-year average; estimates discontinued for 1965.

Prepared by J. E. Welch, Department of Vegetable Crops, University of California, Davis.
NUTRITIONAL VALUE

Carrots are one of our most popular root crops both as a raw and a cooked vegetable. According to MacGillivray and others (18), the carrot ranks high in food production efficiency. Measured by this criterion carrots are placed in group 2 by these investigators, along with onions, tomatoes, and beets. Carrots with tops were used in making these analyses and calculations. If topped carrots had been used, they would have ranked even higher in food production efficiency.

Watt and Merrill (26) reported that raw carrots have the following composition:

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascorbic acid</td>
<td>8 mg.</td>
</tr>
<tr>
<td>Calcium</td>
<td>37 mg.</td>
</tr>
<tr>
<td>Energy</td>
<td>45 calories per 100 gm.</td>
</tr>
<tr>
<td>Iron</td>
<td>7 mg.</td>
</tr>
<tr>
<td>Niacin</td>
<td>.6 mg.</td>
</tr>
<tr>
<td>Protein</td>
<td>1.1 gm.</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>.05 mg.</td>
</tr>
<tr>
<td>Thiamine</td>
<td>.06 mg.</td>
</tr>
<tr>
<td>Vitamin A</td>
<td>11,000 I.U.</td>
</tr>
<tr>
<td>Water</td>
<td>88.2 percent.</td>
</tr>
</tbody>
</table>

Compared with other vegetables, carrots rank high in vitamin A; about average in food energy, iron, and protein; and low in ascorbic acid, niacin, riboflavin, and thiamine.

The vitamin A value fluctuates considerably with the variety and stage of maturity. The Imperator type, used principally for marketing as a fresh vegetable, has about 11,000 I.U. per 100 gm. at market maturity, whereas the vitamin A values of the Chantenay and Danvers types used for processing increase to 17,000 and 38,000 I.U., respectively, at harvest. This increase in vitamin A is due chiefly to age.

TAXONOMY, ORIGIN, AND DOMESTICATION

Carrots (Daucus carota L.) belong to the Umbelliferae, the carrot family. Besides carrots, this family includes such vegetables as celery, celeriac, and parsley. Nearly 60 species of Daucus have been described. About half of them are subspecies or forms of the polymorphic species D. carota. Not much is known about the systematics of Daucus and closely related genera. Taxonomists have largely avoided such investigations, probably because the genus is difficult taxonomically, most populations are weedy, and there are numerous semicultivated and cultivated forms.

Information about the origin and domestication of the carrot is meager. Since there is no archaeological record, the information has to be reconstructed from the written record and contemporary paintings. The older literature on carrots is fragmentary and unreliable. Historically the carrot was used chiefly for medicinal purposes. It was not widely known as a food plant until the beginning of the 20th century. DeCandolle in his classical work on cultivated plants published in 1882 barely mentions the carrot, although many minor crops are discussed in detail.

Banga, of the Institute of Horticultural Plant Breeding, Wageningen, Netherlands, published several articles on the origin and domestication of the carrot. He (2) reported that the carrot with purple roots (Carrots with purple roots owe their deep purple or dark red to chemical substances called anthocyanins, which are responsible for the dark red of table beets, red cabbage, and many flowers. On the other hand, yellow- and orange-fleshed carrots are mostly dependent on chemical substances known as carotenoids. Anthocyanins and carotenoids are very different chemically and physiologically.) was domesticated in Afghanistan and spread to the eastern Mediterranean area under Arab influence in the 10th to 12th centuries and to western Europe in the 14th and 15th centuries. Carrots with purple roots reached China at the end of the 13th or the beginning of the 14th century and Japan in the 17th century. He suggested that a yellow variant spread simultaneously with the purple-rooted anthocyanin type and that carrots with white and orange roots are mutations of the yellow variant.

This last suggestion is supported by Imam (15). See the section on Breeding and Genetics in this handbook. The predecessors of our common orange-fleshed carrot were developed in the Netherlands commencing in the 17th century.

1 Carrots with purple roots owe their deep purple or dark red to chemical substances called anthocyanins, which are responsible for the dark red of table beets, red cabbage, and many flowers. On the other hand, yellow- and orange-fleshed carrots are mostly dependent on chemical substances known as carotenoids. Anthocyanins and carotenoids are very different chemically and physiologically.

² Italic numbers in parentheses refer to Selected References, p. 36.
Russian investigators under N. I. Vavilov, the great geneticist and plant geographer, intensively studied the many forms of wild and cultivated carrots in the late 1930’s. Like Banga, they indicated that the purple-rooted anthocyanin carrot was originally domesticated in Afghanistan and then spread to the shores of the eastern Mediterranean, where it hybridized with a local species, Daucus maximus Desf. The Russian workers suggested that the white-, yellow-, and orange-fleshed carrots may have been segregated from this complex mixture of hybrids, and these were later cultivated. Obviously this hybridization theory directly conflicts with the mutation theory proposed by Banga. More information is needed. However, Banga’s proposals are more fully documented than the speculations advanced by the Russian investigators (Mackevici (19), Zagorodskikh (28)).

MORPHOLOGY

The wild carrot is normally an annual, and the cultivated varieties are usually biennials. The latter plants produce a fleshy taproot and a rosette of leaves the first year. The second year the flower stalk and seeds develop.

**Roots.**—The edible part of the plant is an enlarged fleshy taproot. It consists essentially of the cortex or phloem and the core or xylem (fig. 1). The most desirable roots are those with a high proportion of cortex to core. Roots with large cores are apt to be woody and lack color and flavor. Some varieties have deeply pigmented cores or appear to be coreless. However, it is impossible anatomically to have a coreless carrot. Carrots are considered a moderately deep-rooted crop. The fibrous root system is fairly extensive, with a maximum spread of 5 feet and a maximum depth of 6 feet.

**Leaves.**—The basal leaves, which form a rosette, are pinnately compound, with long petioles expanded into a sheath at the base. The leaves on the upper part of the stem are usually smaller and less dissected.

**Stems.**—The upper part of the fleshy storage organ consists of stem tissue, the enlarged hypocotyl. It is from this platelike stem that the leaves originate. Normally during the second year the stem elongates and produces rough, hispid branches 2 to 6 feet high. These flower-bearing stems or stalks have enlarged nodes and hollow internodes.

**Inflorescence.**—The inflorescence is a terminal compound umbel subtended by several long-lobed, involucral bracts. Such an inflorescence consists of a primary umbel and a system of second-, third-, and fourth-order umbels, defined by the succession in which they arise from the main stem. The primary umbel is the largest and may be 5 to 6 inches in diameter. Thereafter the umbels decrease in size

---

**Figure 1.**—Longitudinal section of carrot taproot, showing its various parts.
as the order number increases. Fourth-order umbels rarely produce many good seeds. The flowers and later the seeds are arranged in a dense mass within the umbel. The surface of the umbel is flat, but becomes cup shaped at maturity.

**Flowers.**—The flowers are perfect, small, and usually with white petals. There are five petals and five stamens. The tips of the petals turn inward when young. The ovary is inferior and consists of two locules, each containing a single ovule. On the upper surface of the ovary is a swollen, nectar-secreting disk, which supports the style and stigma.

**Seeds.**—The carrot seed is actually one-half of a dry indehiscent fruit. Botanically it is termed a mericarp. It is flattened on one side, but the opposite side has longitudinal ribs, some of which bear barbed spines. These spines have to be rubbed off before the seeds can be used in a planter.

---

**BREEDING AND GENETICS**

Work on carrot breeding and genetics largely centers around efforts to understand the genetic mechanism governing male sterility and its subsequent manipulation to produce F₁ hybrid seed for growing the commercial crop. Much attention has been given to developing breeding techniques, selection for carotene content, and inheritance of root color.

Male sterility in carrots was first reported in 1886, but not until Welch and Grimball (27) in 1947 found a male-sterile plant in the variety Tendersweet was the possible use of this character to produce F₁ hybrids seriously considered. In more recent investigations, male-sterile individuals have been found in many cultivars and in at least two populations of wild carrots.

The genetic basis of male sterility in carrots probably involves two systems, perhaps others. Although the method of inheritance of male sterility has not been resolved completely, investigators have uncovered much useful information and suggested hypotheses that must be proved or disproved before an overall solution to the inheritance of male sterility can be offered. In spite of the absence of a precise explanation for the inheritance of this character, breeders have not hesitated to use it to develop hybrid varieties, several of which have been released. Many breeders, both public and private, are engaged in developing suitable lines and techniques to make this method of breeding simple and practical.

In 1961 Thompson (24) reported the first extensive investigation of male-sterility inheritance in carrot using several sources of male sterility. He suggested that male sterility in populations obtained from a male-sterile wild carrot and from the variety Tendersweet are controlled by the interactions of a cytoplasmic factor with at least two and most probably three duplicate dominant nuclear genes. In addition, an epistatic factor or factors, assumed to be dominant, make individuals male fertile that have sterile cytoplasm, provided they are not homozygous dominant for at least one gene at the Ms loci.

As Hansche and Gabelman (11) pointed out, critical tests of this rather complex hypothesis have not been reported. They confined their studies on the inheritance of male sterility to a narrow base. They used material originating from P.I. 169486 and the varieties Tendersweet and Imperator with a single cytoplasmic background. Their data indicate that a dominant gene, Ms₄, and a recessive gene, m₈s, control segregation for male sterility in this material. They were not able to determine whether Ms₄ is allelic to any of the three dominant genes postulated by Thompson as controlling segregation for male sterility in the variety Tendersweet. However, they did find support for the suggestion of Welch and Grimball (27) that male sterility in Tendersweet is inherited as a dominant character.

Banga and his coworkers (3) reported a complex series of experiments on the inheritance of male sterility. The male-sterile lines used were derived mainly from Amsterdam Forcing but also from three other varieties. The male-fertile lines used were also derived from Amsterdam Forcing. Eight hypotheses were tested. The hypothesis best fitting the data is in general not unlike that proposed by Thompson, except Banga introduced the idea of fertility restoring nuclear genes. Banga and his coworkers proposed the hypothesis that male sterility in carrots is controlled by two duplicate nuclear genes, one dominant and
one recessive, interacting with a cytoplasmic factor and two complementary dominant nuclear genes that restore fertility.

It is claimed that the results of Hansche and Gabelman support this hypothesis, as do those of Thompson. Several critical experiments and much work will be required to confirm or disprove these suggestions, but investigators apparently are fast approaching a genetic solution to this problem.

In other recent plant-breeding and genetic studies, Dickson and others (8) found that a specified number of hours below 50° F. was satisfactory for determining the cold exposure needed to induce bolting in carrots. This information was developed into a useful breeding procedure to screen segregating populations for annual bolting. Young seedlings were subjected to 650 hours below 50° during the first 2 months after germination, followed by 3 months of observation to allow full expression of the bolting habit.

Cracking is a serious problem in carrots, particularly in varieties of the Nantes types. Natural cracking is influenced by environmental variables, such as soil moisture, root age, and wide spacing. Dickson (7) developed a technique for distinguishing those plants that are genetically cracking, but phenotypically noncracking, from phenotypically cracking plants. By piercing the root with a knife the cracking tendency is immediately apparent. Dickson concluded that this tendency is governed by a single dominant gene.

Selection for sugar and dry-matter content of the roots is of interest to carrot breeders because of the effect of these two factors on yield and quality of both the fresh and the processed product. Carlton and Peterson (5) found after analysis of sugars and dry matter in single roots of eight commercial and two experimental varieties that there was much more variability among individual roots of a variety than among variety means. Also, by selection and inbreeding, lines could be established that were higher or lower and more uniform in sugar and dry-matter content than the varieties from which they were derived.

Furthermore, the regression curves of total sugars and dry matter on soluble solids indicate that selection within a breeding line can be based on the refractometer reading of total solids in the roots. In another part of this study, Carlton and Peterson showed that soluble solids and dry-matter content are positively correlated with total sugars and nonreducing sugars, but only negative or non-significant correlations result with the nonreducing sugar fraction.

Genetic studies by Imam (15) and Imam and Gabelman (16) on the inheritance of carotenoids in carrot indicate a single gene difference between light orange and orange roots: light orange is dominant. Monogenic segregations were obtained in a cross between a light orange and a light yellow (lemon colored) line, with light yellow dominant over light orange. Also, the cross between lemon yellow and dark orange gave a yellow F₁, indicating dominance of lemon yellow.

Analyses of the roots of the parents in these experiments showed total values of 71 to 107 μg. of carotene per gram of fresh weight. Alpha- and beta-carotenes comprised about 90 percent of the total carotenoids; xanthophylls and colorless polyenes made up the remainder. Varieties differed markedly in the amounts of alpha- and beta-carotene. In Imperator and Tendersweet varieties the amount of alpha-carotene was approximately two-thirds the amount of beta-carotene and in Chantenay about one-half.

Laferriere and Gabelman (17) reported the results of an extensive study to determine the inheritance of root color, total carotenoids, and alpha- and beta-carotenes. They isolated and described five color phenotypes and the amount of total carotenoids and alpha- and beta-carotenes associated with each phenotype. Of the colored phenotypes—white, yellow, orange tinge, intermediate orange, and orange—white was dominant. Genes for the white phenotype almost completely inhibited the synthesis of alpha- and beta-carotenes in the F₁ progenies. White and yellow differed by a single gene, but the relationship between the yellow phenotype and the orange classes was more complex. There was a close relationship between color intensity, total carotenoids, and alpha- and beta-carotenes. In one orange × yellow cross, Laferriere and Gabelman found that complementary gene action produced purple roots and that the color of the phloem and xylem is independently inherited.

Imam found, as have others, that inbreeding sharply reduces vigor and viability in carrots. In his experiments, inbred lines could not be maintained after five generations of inbreeding. On the
other hand, no off-type or off-color roots were obtained after inbreeding, indicating his parental lines were homozygous for genes controlling shape and color. Another interesting observation showed that grafting shoots of white or yellow roots on orange roots and the reciprocal grafts did not induce a color change in the roots, indicating that the genotype of the shoot or hypocotyl had no effect on root color. These results suggest that synthesis of carotenoids is in the roots.

**VARIETIES**

Numerous varieties of orange-fleshed carrots have been developed, mostly by seedsmen. Babb and others reported 389 names that have been applied to orange-fleshed varieties. Probably more than half are synonyms of older well-known varieties. They classified the orange-fleshed carrots into nine major types based on their general or outstanding characteristics. If this classification is followed, only the Chantenay, Danvers, Imperator, and Nantes types are important for the commercial carrot grower in this country.

**Chantenay**

Varieties of the Chantenay type are used chiefly for processing, but they are a good home and market-garden type of excellent quality, particularly for canning and storage. Characteristics: Midseason maturity; large, strong foliage; roots 4½ to 5½ inches long by 1½ to 2 inches in diameter; taper to blunt end; deep-orange cortex and core. Royal Chantenay (fig. 2) is a widely adapted variety of this type. It is primarily used for processing, but it is well suited for the home garden. Red Cored Chantenay is another variety of this type that has been extensively used and is still popular.

**Danvers**

The Danvers type is used for fresh market and processing. Characteristics: Midseason maturity; large, strong foliage; roots 5 to 6 inches long by 1½ to 1¾ inches in diameter; taper to short tapered or slightly rounded end; deep-orange cortex and a slightly more yellow core. Danvers 126 (fig. 3) is a popular variety of this type.

**Imperator**

The Imperator type was bred for fresh-market use and is extensively employed for this purpose. It is reputed to be a cross between Nantes and...
Chantenay and was introduced in 1928 by the Associated Seed Growers. Characteristics: Mid-season to late maturity; large, strong foliage; roots 6 to 7 inches long by 1 to 1 1/4 inches in diameter; taper slightly to short tapered end; deep-orange cortex and slightly less pigmented core. Long Imperator 58 (fig. 4) is one of the best varieties of this type.

**Figure 4.—Typical roots of Long Imperator 58 at prime marketable stage of maturity. (Courtesy of Asgrow Seed Co.)**

**Nantes**

Nantes is a superior type for home and market-garden use because of excellent quality and early maturity. Characteristics: Generally too fragile for shipping and processing; short, sparse, brittle foliage; roots 4 1/2 to 6 inches long; nearly cylindrical, with blunt end; deep orange-red cortex and core; excellent texture and flavor. There are several strains of this type, most of them sold under the variety name “Nantes.” Unfortunately there is a high incidence of green shoulders, light-orange cortex, and yellow core in strains of this variety. (Fig. 5.)

**Hybrids**

Only a few hybrids have reached commercial channels, but there is abundant evidence that they will supplant open-pollinated varieties as soon as the technology of combining the best of the inbred lines with provision for adequate seed production can be worked out. The uniform, smooth, highly colored roots produced by superior hybrids (fig. 6) cannot be duplicated by open-pollinated varieties. Plant breeders are working to develop hybrids using the male-sterile material now available. Judging from their progress, we can undoubtedly look forward to hybrids of all the important types.

**Figure 5.—Typical roots of Nantes 99 at prime marketable stage of maturity. (Courtesy of Asgrow Seed Co.)**

**SEED PRODUCTION**

Since 1960, marketing statistics show that the domestic supply of carrot seed can be produced on about 2,000 acres annually. Seed requirements of the industry fluctuate between slightly less to slightly more than a million pounds each year. Since domestic production of carrot seed normally supplies the needs of the industry, imports over the past decade have been negligible.

Production of carrot seed is restricted usually to warm, dry areas where summer and fall rains...
are uncommon. Most of the carrot seed crop is produced in central California, southern Idaho, and adjacent areas of eastern Oregon (fig. 7).

Carrot seed producers have the choice of two cultural procedures: Seed-to-seed, where the crop is treated as an annual, and root-to-seed, where a biennial system is followed.

If the seed-to-seed method is used, the seed is planted and produced in one location. This method is less expensive and the yields are usually higher than the root-to-seed method. However, it has certain disadvantages, mainly because there is no opportunity to systematically rogue the crop. It places a heavy burden on the stock-seed source, and only stock seed of highest quality and purity can be used. Also, at the time the crop is planted it is sometimes difficult to obtain good stands and thus yields are curtailed.

The root-to-seed method is followed by most seedsmen. Plantings are usually made in late spring. After the tops are mowed, the stecklings are lifted in the fall. After a period of controlled storage (32° F. and 90- to 95-percent humidity is considered ideal), the stecklings are transplanted in March or April for the seed crop. At this time all off-type roots can be discarded, along with roots that are cracked, stunted, diseased, or otherwise undesirable. If the stecklings are grown for stock seed, the internal color and core can be checked by slicing the lower tip of the root longitudinally. Internal greening of the shoulder-core area can be examined by making a slanting slice through the shoulder or crown.

Cultural practices for seed production, such as fertilization and irrigation, are similar to those used for producing a crop of market carrots or can be easily adapted. Special precautions must be taken to manage the soil moisture properly after transplanting the young stecklings in the production field, because the roots are highly susceptible to various rots at this stage of development.

Effective weed control is imperative for satisfactory seed yields. Weeds must be controlled in the steckling seedbed and during early growth of the young stecklings after they have been transplanted. Weed control with Stoddard solvent and perhaps other herbicides can be used on seed crops more freely than if the product were intended for human food.

Hawthorn and others (13) studied the pollination requirements for carrot-seed production. Their results clearly show that an adequate source of insect pollinators is necessary for high yields and quality seed. They stated that yields and pollinator populations in open plots, compared with plots caged with bees, indicate that insect populations under natural conditions are not always sufficient for high seed yields. Therefore when the natural supply of pollinators is inadequate, supplementary colonies of honey bees should be supplied and, if feasible, bloom from competing crops should be reduced.

Another requisite in the production of quality carrot seed is to have production fields of each variety well isolated from each other because carrot flowers are readily cross-pollinated. Thompson
Figure 7.—A carrot field in full bloom.  (Courtesy of Pieters-Wheeler Seed Co.)
showed that in the carrot field more than 95-percent natural cross-pollination occurs. For this reason, distances of 1 mile or more are required for satisfactory isolation.

Seed yields vary tremendously depending chiefly on varieties and spacing. Hawthorn and Pollard (14) estimated that seed yields of such varieties as those of the Chantenay type usually are 500 to 600 pounds per acre at 3- by 3-foot spacing and 800 to 1,000 pounds at 1- by 3-foot spacing. Conversely, seed-to-seed planting of the same varieties may yield as much as 1,200 pounds. Seed yields of the less vigorous varieties such as the Nantes type are generally less than 500 pounds, whereas the more vigorous varieties such as the Danvers type yield more than 800 to 1,000 pounds.

Carrot seed is normally harvested when the secondary heads are fully mature and the third-order umbels have turned brown. Harvesting is done by handpulling the plants. They are placed in windrows, and after curing they are moved to a stationary thresher for processing. An alternative method is to use some type of combine harvester that harvests in one operation. After threshing, the seed must be milled before it can be used in planters. This involves rubbing the seed to remove the spines and removing chaff and dust in a screen-fanning mill.

**SOIL REQUIREMENTS**

The choice of soils is one of the most important decisions the carrot grower has to make. Carrots respond differently on each soil type to irrigation and fertilizers. Carrots can be grown on a variety of soil types, but deep, well-drained, friable sandy loams or organic soils such as muck or peat are the most desirable.

In the East and Middle West, carrots are grown on both organic and medium-textured mineral soils, but the major part of the crop is planted on organic soils. Carrots can be grown successfully on either soil type if managed properly and if the appropriate variety is used.

Carrots of excellent quality and yield can be grown on heavy soils in the desert inland valleys of Arizona and California and on dark, silty loams in the Salinas Valley of California.

The sandy loams and organic soils are the easiest to manage and till. Also, much less crusting and compaction are associated with these soils and thus permit maximum opportunity for normal root development. Crusting can adversely affect emergence of the young seedlings, and compaction can have harmful effects on root shape.

In general, light mineral soils and soils of organic origin mature a crop with smoother roots than heavier soils. For this reason, lighter soils are usually preferred for fresh-market carrots. Silt loams and clay loams can be used to grow carrots for processing, because shape and smoothness are not so critical as for fresh-market carrots. Heavy soils, however, have higher water-holding capacity and usually greater fertility than comparable lighter soils. These factors make for superior yields so necessary in the production of carrots for the processor.

Carrots require soils of average depth. This means the roots may occupy the soil to a depth of about 4 feet. The soil should be free of nematodes and all trashy material that might interfere with normal root development.

Since carrots do well on soils with a pH of 6.5 to 7.8, soils with a slightly acid or a slightly alkaline reaction are about equally suited for carrot production. However, this statement has to be qualified by indicating that tolerance to slight alkalinity applies only to native western soils where pH 7 or above is common. For example, good yields of carrots have been obtained in the Salinas Valley of California on soils with a pH of 8.1 to 8.2. In the naturally acid soils of the Eastern United States, adjusting the soil to pH 7 might cause disastrous side effects such as overliming, accompanied by an imbalance of nutrient elements. Carrots are classified as a moderately salt-tolerant crop, along with other vegetables such as cantaloup, squash, lettuce, and spinach.
CARROT PRODUCTION IN THE UNITED STATES

CLIMATIC REQUIREMENTS

Carrots are a cool-season crop. The roots are not damaged by mild frosts, but the tops are frost tender. Experimental work suggests that for optimal growth of both roots and tops the temperature should be between 60° and 70° F. Carrot seed is often planted and the roots are harvested when temperatures are higher. In general, planting and harvesting at extreme temperatures are not considered desirable and should be avoided if possible. High temperatures, for example, can result in poor emergence, or the young seedlings may become restricted at the soil line, and then the roots will be badly misshapen and later unmarketable. At harvest, high temperatures make marketing of a high-quality product difficult because the roots do not easily regain turgidity after prolonged dehydration, and more cooling is needed to bring them to desirable postharvest temperatures.

Effects of Temperature on Root Development

The effects of temperature on carrot root development are fairly well established. Most of the information is from uncontrolled observations and impressions, but there is some good experimental work to support many of the common observations (4).

The carrot root develops best from the standpoint of shape and color at 60° to 70° F. Root shape is more nearly typical for the variety when grown at a relatively uniform temperature near 67°. Under artificially controlled conditions, a constant greenhouse temperature of 65° was best for typical root development of the variety Red Core Chantenay. Other varieties probably have different temperature requirements, particularly some hybrids that may have a narrow range of temperature adaptation.

When grown at an average temperature of about 55° F., carrot roots were longer and more slender than typical, and at a constant temperature of 75°, they were shorter and more stubby than typical. Also, alternating average temperatures of 45° at night and 65° during the day produced longer, more slender roots compared with those cultured at a continuous average temperature of 65°. If the roots were grown at 65° until root enlargement had commenced, followed by temperatures of about 45°, the upper part was normal, but the lower part remained small, tapering off to a long, constricted taproot.

Prolonged high temperatures during later development of the carrot root not only retard growth and depress yields but can cause undesirable flavors. Also, high temperatures increase the woody character and coarseness of the root flesh. On the contrary, low temperatures tend to produce long, slender roots of much lighter color than typical. Also, extremes of high and low temperatures can interfere with the normal rounding of the root base of such types as Nantes and Chantenay. The result is a decided tapering at the base where these types are ordinarily rather stump rooted.

Effects of Environment on Carotene Content

Carotene is the principal pigment in the roots of orange-fleshed carrots. It is the precursor of vitamin A in the animal body. Highly colored roots are more nutritious and more desirable than light or poorly colored ones. Reasonably rapid methods are available for the quantitative evaluation of the carotene content of plant tissues. With modern methods, selection for increased carotene content of the root can be accelerated considerably.

Conditions governing the production of maximum carotene content are not completely understood, but certain principles are evident from the work thus far completed. For instance, carotene content generally decreases at continuous temperatures of 70° and below 60° F. Also, roots grown under a regime of cool nights (45°) alternating with warm days (65°) developed more carotene than roots maintained at a continuous temperature of 45°. Soil moisture also has a pronounced effect on the development of carotene. Increasing soil moisture from a low to high percentage markedly decreased color. These data suggest that poorly drained or waterlogged soils should be avoided for carrot culture. Carotene content was not increased in soils of moderate fertility by adding plant nutrients, but a marked deficiency in any plant nutrient did decrease carotene content.

Photoperiod is another environmental variable
with a marked effect on carotene content. A photoperiod of only 7 hours resulted in much less carotene compared with one of 14 hours. Increasing the photoperiod from 9 to 14 hours, however, had little or no effect on carotene content.

Age of the root is an additional factor with a significant effect on carotene content. Color increases in the young root up to about 100 days after emergence, followed by a stable period in which there is little change in either direction. Some experimental work indicates a general tendency of most varieties to increase in carotene content during storage. Specifically, there was an increase in carotene content per 100 gm. of dry weight up to 20 weeks of storage, followed by 30 weeks at which carotene content remained fairly stable.

FIELD MANAGEMENT

Success in producing a satisfactory carrot crop will ultimately depend on skillful and timely management by the grower of such cultural practices as land preparation, planting, fertilization, irrigation, and weed control.

Land Preparation

In land preparation construct a level seedbed, with soil that is not too rough or cloddy but not so fine that it will puddle or crust. Provide optimum water penetration and soil aeration. In western soils plowing to a depth of 12 to 15 inches is suggested, followed by such tillage operations that will terminate in a smooth, level field, free of trash and suitable for bedding and planting. There should be no physical obstruction to root development for a depth of 2 feet or more. A carrot root is easily misshapen if it comes in contact with any obstruction. It is frequently unusable after contact with undecomposed woody material in organic soils.

In eastern and midwestern soils with a shallow A horizon and a difficult B horizon, deep plowing is not recommended. Also, where organic soils are susceptible to wind erosion, it is best to leave the surface relatively rough. If the surface is finely divided as a result of excessive tillage, it is easily eroded by wind.

Two warnings concerning land preparation must be stressed. First, the land should be free of all irregularities at time of bedding and planting; otherwise control of soil moisture for establishing satisfactory stands and uniform growth of young plants is impossible. Second, avoid excessive tillage operations; not only are they costly but they adversely affect soil structure.

Planting

Planting dates for carrots will vary depending on temperature, variety, time at which the grower desires to market the crop, and perhaps other factors. In most districts, except the arid, inland valleys of Arizona, California, and Texas, carrots are planted as early in the spring as the soil can be worked. Usually planting commences about April 15 and continues until mid-July. In the Salinas Valley of California, however, planting commences in January and continues through July. In the desert valleys the crop for midwinter and early-spring harvest is planted from about August 1 through October. In the Salt River Valley of Arizona carrots for spring harvest are planted in February and March.

Carrots require between 85 and 150 days from planting to harvest depending on the planting date. For some hybrid varieties, the time from planting to harvest is much shorter than for comparable open-pollinated varieties.

Carrot seeds are small compared with other vegetable seeds, and emergence is slow and irregular. The young seedlings are small, weak, and fragile. They lack vigor until the first true leaves appear. For these reasons, planting techniques are extremely important. Faulty planting can easily lead to spotty stands, poor spacing, or other defects that result in low yields of poor-quality roots.

In the West, Southwest, and other areas where irrigation is needed for this crop, carrots are planted on raised beds similar to those used for other vegetable crops. The beds are 4 to 8 inches high after smoothing, 40 to 42 inches from center to center, and 18 to 20 inches across the top. The seed is planted near the edge of the bed, usually with equipment that shapes the bed and plants the seed in a single operation (fig. 8).
Splatter-type planting shoes are sometimes used to scatter the seed at random in a band 3 to 4 inches wide. The final result is two broad rows of plants on each bed, spaced 10 to 12 inches apart. Also planters are used with two groups of three to four shoes. The shoes in each group are 1½ to 2 inches apart on center and the two groups 9 to 10 inches apart. Thus each bed will have six to eight rows of plants grouped in threes or fours with 9 to 10 inches separating the rows.

The purpose of these modifications of conventional vegetable seed planters is to produce a band of three or four rows of plants 3 to 6 inches wide so as to dispense with the necessity of thinning, yet produce heavy yields with a minimum of twisted, misshapen roots.

In the East and Middle West standard spacing is 16 inches between rows for both fresh-market and processing carrots. The ideal spacing for maximum yield may be closer than 16 inches, but this is about the minimum in order to use present-day harvesters. Investigations are underway to determine ideal spacings between and in rows for maximum marketable or usable yield per acre for both fresh-market and processing carrots. Efforts are also underway to explore different methods of harvesting to accommodate closer row spacing. For 16 inches between rows, a shoe that spreads the seed over a 2- to 4-inch band is used. There should be about 12 to 15 plants per linear foot of row.

The seed is normally covered to a depth of one-eighth to one-half inch depending mostly on soil type and moisture availability. In heavy soils shallow planting is best; in lighter soils that dry out quickly deeper planting is suggested. A packer wheel that firms the soil around the seed is usually drawn behind the planting shoes.

Carrot seed is generally graded into large and medium. For a crop to develop uniformly from emergence to harvest it is best to use sized rather than unsized seed. A mixture of large and small seed is apt to cause unevenness in emergence and development, which carries over into the harvest period.

For fresh-market carrots, the rate of seeding per acre varies from 2½ pounds to as much as 5 pounds depending on the season, soil condition, type of planter, and whether single or paired rows are used. Thirty to forty seeds per foot of row are optimal under most conditions. Based on data from
the Salinas Valley of California, 30 to 40 plants per foot of bed are optimal for highest yield of the Imperator type. For this size plant population, about 3 pounds of seed per acre are required. Band planters drop from 50 to 60 seeds per foot and increase the rate up to 5 pounds per acre. Use more seed if germination is near the minimum allowable of 55 percent. For processing varieties, the rate of seeding ranges from \( \frac{3}{4} \) to \( \frac{1}{2} \) pounds per acre on muck soils in Michigan and Wisconsin.

Harrington (12) found that the maximum percentage of normal carrot seedlings (93–96) is produced at 50° to 86° F. but drops off sharply both above and below these optima. On the other hand, carrot seed required from 6 to 8 days to emerge at 68° to 95°, whereas 17.3 and 10.1 days, respectively, were required at 50° and 59°.

**Fertilization**

The carrot plant is an efficient feeder because the root system extends over a broad area and fertilizer is readily utilized in the vicinity of the roots. Zink (unpublished data) calculated the pounds of minerals removed per acre from the soil by a crop of carrots (table 2). Probably the total amounts given in this table for nitrogen, phosphorus, and potassium approximate the quantities removed in other soil types and in other areas for fresh carrots. The amount of these three minerals removed by a crop of processing carrots would be substantially increased over that recorded for fresh-market carrots.

The management of fertilization for carrot production will vary with soil type, location, and other environmental variables. Hence, commercial fertilizer recommendations need to be tailored to specific soil requirements and to the locality involved. Nevertheless some general principles can serve as useful guides in maintaining adequate soil fertility for high-quality, high-yield carrot production.

Mineral soils should be supplied with liberal amounts of organic matter through either green manures or well-composted animal manures. Never use fresh animal manures because they markedly increase the number of forked roots in carrots.

The normal requirement of mixed fertilizer for organic soils is about 700 to 1,000 pounds per acre. It should be low in nitrogen, medium in phosphoric acid, and medium to high in potash. Typical formulations are 3–10–10, 3–9–8, 2–8–16, and 5–10–15. Specific recommendations for fertilizer application to organic and mineral soils, based on available phosphorus and potassium and depending on the anticipated nitrogen deficit in the soil, have been worked out for carrot culture in Michigan and perhaps for other midwestern and eastern States.

For the inland, arid valleys of the Southwest, phosphorus is the key element. Usually apply 300 to 400 pounds of treble superphosphate (48 per-

<table>
<thead>
<tr>
<th>Variety and plant part</th>
<th>Minerals per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Long Imperator 11:³</td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>59</td>
</tr>
<tr>
<td>Roots</td>
<td>51</td>
</tr>
<tr>
<td>Total</td>
<td>110</td>
</tr>
<tr>
<td>Long Imperator 58:⁴</td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>69</td>
</tr>
<tr>
<td>Roots</td>
<td>61</td>
</tr>
<tr>
<td>Total</td>
<td>130</td>
</tr>
</tbody>
</table>

³Grown on Salinas silty clay loam, with growth period of 126 days.
⁴Grown on Salinas fine sandy loam, with growth period of 132 days.

---

1From Zink (unpublished data).
2N = nitrogen, P = phosphorus, K = potassium, Na = sodium, Ca = calcium, Mg = magnesium.
3Grown on Salinas silty clay loam, with growth period of 126 days.
4Grown on Salinas fine sandy loam, with growth period of 132 days.
cent phosphoric acid, $P_2O_5$) per acre by broadcast immediately before planting. Then apply 125 to 175 pounds of nitrogen per acre as a side dressing early in the growing season. When the roots are about the size of a lead pencil and commencing to grow rapidly, 30 to 40 pounds of ammonia per acre may be added to the irrigation water. Of the dry fertilizers, do not use sodium nitrate in desert soils because of the adverse effect of the sodium ion on soil structure and salt accumulation. Also, crops grown on desert soils of the Southwest do not respond to applications of potash. For this reason, fertilizer formulations with potash are not generally recommended.

On mineral soils in the Salinas Valley, apply about 40 pounds of nitrogen and 200 pounds of phosphoric acid per acre as a preplant treatment. Later apply 100 pounds of nitrogen per acre as a side dressing, using 30 to 40 pounds in each of three applications. In the Northwest, 60 to 100 pounds of nitrogen, 60 to 150 pounds of phosphoric acid, and 60 to 120 pounds of potash per acre are recommended. In addition, the soils of some districts (e.g., Willamette Valley of Oregon) require small amounts per acre of sulfur (15 to 20 pounds) and boron (3 to 5 pounds).

Fertilizers can be applied broadcast, banded, top dressed, side dressed, or in the irrigation water. A combination of broadcasting, banding, and gas metered into the irrigation water is a common practice. The preplanting application is broadcast or drilled about 4 inches deep into the ground. In broadcast applications where furrow irrigation is used, much of the fertilizer will be distributed in the beds to a depth of 4 inches when the beds are formed. When using dry fertilizers as a side dressing, place the material in a band about an inch wide between the seed row and the irrigation furrow at a depth of one-half to 4 inches so that it is made available immediately to the young seedlings.

Organic soils are often deficient in micronutrients important in carrot production. These include manganese, boron, and copper. The application of these elements to the soil should be considered good insurance against a possible deficiency. Should a deficiency occur during crop growth, it can be corrected by applying the indicated micronutrient in a foliar spray.

### Irrigation

Carrots require an evenly distributed and abundant supply of moisture over the growing season. They require much higher soil moisture for good emergence than most other vegetables. Even in districts where irrigation is not usually necessary, supplemental sprinkler irrigation at the correct time can promote seedling emergence, reduce wind erosion, decrease freezing damage, prevent burnoff of young seedlings during extreme heat, and will often increase yields and improve quality.

In organic soils where moisture is regulated by the height of the water table, it is suggested that the water table be kept at 30 to 36 inches below the soil surface. Additional moisture provided by the solid-set irrigation system is commonly used on organic soils to promote seedling emergence, control wind erosion, reduce freezing injury, and prevent burnoff of young seedlings from high temperatures. With the solid-set system the irrigation lines are laid immediately after planting and allowed to remain until the plants are large enough so there is little danger of wind damage, normally 4 to 6 weeks after planting. The system can then be dismantled and used with other plantings.

If additional moisture is needed for germination and emergence, one-half to 1 acre-inch of water will provide sufficient moisture around the seed. To control wind damage, keep the soil surface damp. Freezing injury usually occurs only in early plantings. It can be prevented by applying continuously one-tenth inch of water per hour until the danger of freezing is past. Burnoff of young seedlings can be minimized by applying one-half inch of water per hour when the air temperature is above 85°F.

In the Southwest where rainfall is not a factor in producing a crop, a preplanting irrigation is normally applied before the beds are made. It serves chiefly to leach the soluble salts from the surface and thus provides a more favorable environment for germination and early growth. There is also the added bonus from preplanting irrigation of germinating weed seeds for subsequent and early destruction. Also, ample moisture is provided in the lower levels of the root zone. After planting, the soil is soaked to field capacity, and another light irrigation may be needed at about the time of emergence to keep the surface soil moist and prevent crusting.
The amount and frequency of irrigation after emergence will vary with the producing area and such factors as soil type, temperature, and age of crop. The grower should strive to maintain an ample, even supply of soil moisture in the root zone. Plants stressed for water have small roots, which are tough, woody, rough, and of poor flavor, whereas an uneven water supply can cause root cracking and malformed roots. There is also danger from overirrigating, particularly during cool weather. Excessive watering may cause the orange-red roots to fade or, even more serious, lead to disease problems.

In the desert valleys of the Southwest about 2 to 2 1/2 acre-feet of water are required for the crop. This means 10 or 12 irrigations spaced at 7- to 10-day intervals. In the coastal valleys 2 to 3 acre-feet of irrigation water are necessary to grow the crop; 3 to 4 acre-inches are applied at 10-day intervals. In the Willamette Valley of Oregon only two to four irrigations are required or about one-half acre-foot.

The grower will find that successful irrigation practice is governed by the condition of the plants. Several methods are used to estimate the need for additional soil moisture. Some of them are highly sophisticated. A simple, easy, accurate method is to use a soil tube. This instrument is inserted in the root zone to a depth of 2 feet or more. The color and cohesion of the extracted soil sample indicate the need for additional moisture.

Weed Control

Carrots are well adapted for effective, economical weed control through the use of chemicals. As a result, chemical weed control is a standard practice. Spray Stoddard solvent (carrot oil) on the young seedlings when they have two to four true leaves and the young root is no larger than one-fourth inch in diameter. This treatment applied at 50 to 100 gallons per acre will kill or suppress most broadleaf weeds and annual grasses. It is most effective if the leaves of the young plants are thoroughly wetted by the spray and it is applied during cool weather or in the cooler part of the day.

Stoddard solvent does not control certain weeds, particularly ragweed. For this reason in the East and Middle West, applications of 1 to 2 pounds per acre of linuron (Lorox) are suggested when the carrot foliage is 3 to 6 inches above ground. Adequate soil moisture and temperatures below 85° F. are best for effective and safe use of linuron.

Weed specialists are working with several other promising materials that are more effective for specific purposes than Stoddard solvent. For these materials, however, timing, tolerances, and residues have not been determined to the point where recommendations can be made.

Chemical weed control is not a substitute for preplanting irrigation to control weeds or precision cultivation to kill late emerging weeds. However, with proper use and careful timing, herbicides are normally so effective that weeds are not a serious production problem.

Even with good chemical control of weeds, some cultivation will be necessary to destroy late emerging weeds and to mulch over soil cracks. For these purposes, shallow cultivation is usually recommended. The final cultivation should distribute the soil so as to cover completely the upper part of the roots. If left exposed, the roots become an unattractive green and are usually discarded as being unmarketable.

Rotations

Carrots are best grown in rotation with alfalfa and such legume cover crops as sour clover and vetch. Do not use legumes that are uncommonly susceptible to nematodes, e.g., Sesbania sp. Other crops that can be used in rotation with carrots are the small grain cereals (barley, wheat, oats), grain sorghums, pasture and hay crops, and some vegetables such as spinach, onions, and sweet corn. Other vegetable crops, for example, celery, parsley, and beets, should be avoided because they aggravate the soil-disease problem by encouraging a buildup of the same soil pathogens that are damaging to carrots.

In the East and Middle West, carrots have been grown on the same land continuously for at least 10 years. This has been achieved by soil fumigation, usually in alternate years. Growers have used prevalence of the root-knot nematode as an index to the need for fumigation. If a few nematodes are found on the current crop, the soil is fumigated before another planting. This continuous and in-
tensive method of production is not encouraged or recommended because of the likelihood of eventual injurious effects from the accumulation of destructive soil organisms and possible toxic residues. However, in some areas the pressure of economic factors is so great and growers have become so specialized that they normally have no other choice except continuous carrot culture.

HARVESTING

Nearly all carrots for both the fresh market and processing are machine harvested. A few markets prefer carrots with the tops intact, but the labor costs for this type of operation are not competitive with those for machine-harvested carrots. Machines for harvesting carrots (fig. 9) are custom built and priced from $3,500 to $5,000. They will harvest from 3 to 5 acres per day and take the place of about 60 laborers.

Machine-harvested carrots are loosened under the row by a lifter device and elevated out of the soil with belts, which grasp the carrot tops. The tops are cut or twisted off and allowed to fall back on the field while the roots are elevated to trucks for bulk transportation, or the trucks are equipped with pallet boxes. The roots are then transported to the packing sheds or the processor. In the eastern sections of the country when carrots are stored for December or early January packaging or processing, pallet boxes are nearly always used. They assure good air circulation throughout the carrots during storage. Also, they are easily handled with a forklift tractor.

Bunched carrots, or those marketed fresh with the tops intact, are loosened and lifted by a tractor, which is fitted with a set of knifelike blades and straddles each bed (fig. 10). A crew of laborers follows the tractor and pulls, sorts, and ties the carrots in bundles of five to seven roots so that the average bundle will weigh 1 1/2 to 1 1/4 pounds (fig. 11).

The bunches are tied together in groups of 10 for transporting to the central packing shed, where they are washed, packed, iced, and loaded into refrigerated railroad cars or trucks.
Packing, Storage, and Processing

Central packing sheds for processing topped fresh carrots for market are designed to wash, size, sort, package, and cool the product with maximum efficiency and minimum amount of hand labor. Generally the carrots are first unloaded into a water vat as they arrive from the field in bulk or in pallet boxes (fig. 12). From the water vat they travel by conveyor through one or two washing operations, then into a sizing machine and past sorters and graders. They are placed by hand in 1-pound consumer-unit, polyethylene film bags (fig. 13). When the bags are filled with washed and sized carrots, they are placed on the conveyor and sent to other workers, who tie or seal the packages (fig. 14).

The 1-pound consumer packages usually contain carrots of two sizes—the small to medium (½ to ¾ inch in diameter) and the medium to large (¾ to 1½ inches in diameter). Carrots of both sizes must be at least 6 inches long. Normally a greater proportion of roots is in the larger group. For
example, in Michigan for an average 10-ton crop, 20 to 30 percent of the carrots are in the small to medium category and the remaining 70 to 80 percent in the medium to large category.

Forty-eight 1-pound packages tied or sealed are placed in a container, usually a wirebound crate, for transportation by refrigerated railroad cars or trucks to terminal markets. The 1-pound polyethylene packages are sold in retail outlets.

Another standard package is the 50-pound mesh or polyethylene master bag containing jumbo carrots (1 1/4 to 2 inches in diameter) (fig. 15). They are sold to restaurants, the military services, schools, and other institutions.

Also, a large volume of carrots is marketed in bulk. The roots are washed, placed in burlap bags, and sold by the ton to repackers. Usually located near terminal markets, repackers sort and grade the roots into the standard packages previously described. The product is then marketed under specific brand labels.
Carrots transported in wooden crates with ice in the package are usually shipped under top ice. Since roots in wirebound crates, fiberboard boxes, and kraft paper bags cannot be cooled to the proper temperature with top ice, they are hydrocooled prior to packaging. Afterward they are shipped in fan cars with bunker ice or in mechanically refrigerated cars. To market a good-quality fresh product, effective hydrocooling before packaging and transit temperatures at or near 40° F. are necessary.

There is little basic research on the transportation requirements for prepackaged carrots. The scanty observations reported thus far suggest that this commodity is difficult to cool in transit. Some preliminary tests show that prompt cooling and low transit temperatures (below 40° F.) are necessary to prevent decay and insure an adequate shelf life for prepackaged carrots. Further research is needed to determine minimum precooling requirements and precise transit temperatures and to evaluate methods of cooling, loading, and icing this commodity to obtain adequate and efficient protection in transit.

If carrots are stored after harvest for late processing, the recommended temperature for long-term storage is 32° F. and a relative humidity of 90 to 95 percent. The primary problems in storage are shrivel and decay of the roots, but under conditions of carefully controlled temperature and humidity, carrots can be kept for 4 to 5 months in reasonably good condition. When stored at 40° to 50°, storage life of the roots is reduced 20 to 25 days, and if kept at 65° to 70°, storage life may be only 10 to 15 days. Sprouting or regrowth of the roots can become a problem, but carrots stored near 32° will sprout much less than those kept at higher temperatures. Only sound, entire roots free of disease and blemishes should be stored.

A problem peculiar to stored carrots is the occasional production of a bitter tasting compound commonly known as isocoumarin. It develops in stored roots in the presence of minute quantities of ethylene gas in the storage atmosphere. Research (6) has shown that ethylene acts as a catalyst for the production of isocoumarin in the presence of oxygen. Pretreatment of the roots in a
nitrogen atmosphere for only 4 days prevented the subsequent synthesis of isocoumarin, even in the presence of air and with or without ethylene.

Some processors are experimenting with individual quick freezing of diced carrots in order to extend the storage period and are obtaining no storage loss. Storage of quick-frozen diced carrots assures uniform quality and a predetermined supply for later processing. For a processor who can use diced carrots to make up the final processed product, this method of storage could be desirable. A wide variety of processed products is on the market. Some require a specific raw-product type or shape to develop the final product.

Industry is trying to improve the quality of both the fresh-market and the processed product. Such characteristics as uniform internal color, absence of green shoulders, good flavor, and high sugar and high nutrient content need improvement and are receiving attention in breeding programs.

DISEASES AND THEIR CONTROL

Carrots are not a disease-prone crop. By using certain accepted practices, disease control will usually be successful. This is especially true of carrots to be sold directly after harvest. However, if carrots are stored, certain fungus rots may cause losses, especially where the crop has been harvested under poor environmental conditions and stored in warm, humid places.

Carrot diseases are caused by various agents, including fungi, bacteria, viruses, and nematodes. Fungi are a group of lower plants that lack chlorophyll; therefore they must get nourishment from other plants, plant debris, or animals. They vegetate in the form of thin mycelial protoplasm and periodically reproduce sexually or asexually by producing spores characteristic of their species. Spore production may be prodigious under favorable weather conditions. Spores are carried long or short distances by air currents to susceptible host plants, where they may cause new infections. Carrot diseases caused by fungi include cercospora blight, alternaria blight, watery or cottony soft rot, and several other storage rots.

Bacteria are microscopic unicellular plants. The largest is about one-tenth mm. in greatest dimension and the smallest is 1/10,000 mm. in length. Bacteria multiply rapidly by fission, or merely splitting in half. They may be rod shaped, spherical, or spiral shaped; however, all plant pathogenic bacteria are rod shaped. Rainy or humid weather favors the spread of bacteria by wind or mechanical means from diseased spots on plants to nearby healthy plants. Infected seeds or other propagative parts as well as certain insects serve as disseminators also. The only important carrot disease due to bacteria is bacterial soft rot.

Viruses are infectious, filterable, obligate parasites with definite incubation periods and the capability of rapid multiplication in susceptible host tissues. Viruses are nucleoprotein in nature and invisible except with an electron microscope. They are spread by insects, infected seeds or other propagative parts, and man's handling of infected plant parts.

For information about nematodes, see section on Nematodes and Their Control.

Field Diseases

Cercospora Blight

This fungus blight or leaf spot is caused by Cercospora carotae (Pass.) Solheim. This disease is distributed worldwide and commonly occurs with the closely related disease caused by Alternaria dauci (Kuehn) Groves & Skolko. Generally cercospora blight occurs earlier in the season than alternaria blight. In the Central and Eastern United States cercospora appears in July and August and alternaria in the fall. Cercospora is severe on young leaves and builds up when plants are relatively young. Alternaria is more pathogenic on old leaves and does not become serious until the plants reach maturity.

Cercospora may attack any part of the leaf, petiole, stem, or floral parts, but primary lesions usually are located along the margin of the leaflets causing a lateral curling (fig. 16). These spots are elongate, whereas the marginal ones tend to be circular. The necrotic area first appearing as a pinpoint spot soon is surrounded by a chlorotic border. Such small lesions coalesce into large areas until the whole leaflet dies. During humid weather the
lower surface of the spot becomes light gray because of hyaline spore masses. The fungus may sporulate heavily on the petiole, where black linear lesions develop. Eventually the petiole may be girdled and the leaf killed.

When floral parts of carrots grown for seed are infected early, they shrivel before the seed is produced. If floral parts are infected later, the fungus may enter the seed and become a threat to next year’s crop. This disease does not affect the fleshy root. Carrots for the fresh market are usually marketed without tops. The absence of tops has reduced tremendously the incidence of cercospora as a disease of carrots.

**Disease Cycle.**—Cercospora overwinters on and in infected plant debris. Conidia are windborne or waterborne. Once on the plant they germinate and penetrate through the stomata. They germinate over a wide range of temperatures with an optimum about 82°F. After 72 to 120 hours, spots appear and new spores are produced. The conidiophores are 2 to 3 microns in diameter, with conidia borne successively at their tips. Conidia are cylindrical and hyaline to slightly colored, many are septate, with cross walls only in a transverse direction. They range from 2.2 to 2.5 by 40 to 110 microns.

**Control.**—Fall plowing to hasten decomposition of infected debris coupled with a 2- to 3-year rotation will aid in controlling cercospora blight. Fungicide treatments with maneb or other dithiocarbamates give excellent results when applied regularly at the first sign of the disease. Alternaria blight can be controlled in the same way.

**Alternaria Blight**

Alternaria blight caused by *Alternaria dauci* (Kuehn) Groves & Skolko is distributed worldwide and occurs commonly with cercospora blight. When conditions favor its growth, the fungus damages carrots severely and parsley, rooted parsley, celeriac, and celery moderately. On carrot alternaria symptoms resemble those caused by cercospora; however, the spots are more irregularly shaped and the dead tissue is darker brown.

Small dark-brown to black spots edged with yellow form along the leaflet margins. As the spots increase in size and number, the entire leaflet will die. In moist, warm weather the leaflets die so rapidly that the field appears frosted. Large lesions on the petioles may result in girdling, which in turn kills the entire leaf without spots developing on the individual leaflets. The fungus is apt to attack older leaves and seldom becomes serious until plants approach maturity, whereas cercospora prefers young leaf tissues. Alternaria may cause damping-off of seedlings and blight of seedstalks. Fleshy roots are not affected by alternaria; however, a closely related species, *Stemphylium radicicium* (Meier, Drechs. & Eddy) Neerg., does cause black rot of the roots.

**Disease Cycle.**—The fungus is spread on and in contaminated seed and overwinters in diseased debris in the soil. The conidia and mycelium are disseminated by wind, water, and splashing rains and on tools. On a susceptible leaf the conidia germinate slowly, requiring 8 to 16 days for germination and penetration. Moisture is needed for germination, but dew is as good as rain. Optimum temperature for growth and infection by alternaria is 83°F. With a favorable environment a
new crop of spores is produced within 14 to 21 days.

Control.—Practical controls are the same as those for cercospora blight. A mane spray schedule is most effective, especially where good coverage is obtained. Some varietal difference for resistance has been demonstrated. D. L. Strider of N.C. State University in 1963 reported Danvers 126 to be slightly less susceptible to alternaria blight than other varieties tested.

Root Scab Complex

Root scab or scab spot is a physiological disease caused apparently by climatic, nutritional, and genetic factors. It has resulted in considerable losses in carrots grown in California, Texas, Arizona, Massachusetts, and perhaps other States. Early symptoms include brown to maroon lesions, which develop into slightly raised pustules or slightly sunken craters with flakes of dead tissues in their centers. Such spots usually appear black and scablike. Constrictions may encircle the root at the point of damage. Lesions most frequently occur at or near the lateral rootlets. They may be few or numerous, separate or coalesced.

The disease was first observed in California in 1937 in the Santa Maria Valley. It was attributed to direct root infection by the bacterial blight pathogen *Xanthomonas carotae* (Kendr.) Dows. A similar disorder was reported in 1941 in California carrots shipped to Chicago. *Fusarium* sp. was isolated and found to have caused the infection.

Grogan and others (10) in cultural, anatomical, and environmental studies of the disease concluded that its etiology was not clearly defined but rather was due to a complex of factors. They found it to be affected by the genotype of the individual plant as well as by many environmental factors. Its occurrence on carrot roots grown in steam-sterilized soil from treated seed indicated the basic cause to be nonparasitic. Steamed or chemically treated soils in certain instances did reduce the prevalence of scab, suggesting that biological factors were involved. The association of scab lesions with ruptured and abnormally enlarged oil ducts and the arrangement of punctate lesions in a line on which oil ducts are occluded indicate that environmental factors favoring the production and accumulation of oil also favor scab. Unknown factors causing deep-seated disruption of root tissues were thought to be involved. Scab is also aggravated by low levels of nutrition.

Storage and Transit Diseases

**Black Rot**

This disease is caused by *Stemphylium radicum* (Meier, Drec. & Eddy) Neerg. It was first discovered in America in 1918 in Massachusetts and on Long Island, N.Y., and reported in 1922. It was present much earlier in Europe but was confused with several other carrot disorders. It probably occurs wherever carrots are grown because it is seedborne. Although carrot is the main host, seedlings of celery, parsnip, and parsley and the seeds of flax and a *Malva* species are reported to be susceptible.

*Stemphylium* is mainly a root pathogen but can also cause leaf blight, slight petiole cankers, and even damping-off of seedlings. Workers in California found that below-ground infection occurs on the roots as small black spots, which are superficial and scablike, or in stubbed or forked roots when the taproot is killed. Symptoms on stored carrots include circular, shallow, slightly depressed lesions on the sides, or if the tip of the root has been invaded, most of the lower part may be rotted (fig. 17). It is black, moist, and with no odor. In moist storage the infection appears as a soft, wet rot. In dry storage the roots have a dry, mealy type decay. The lesions are characterized by discrete black margins, which separate diseased from healthy tissues. On the crown the rot generally penetrates rather deeply into the core.

On seedlings both root and hypocotyl may turn black while the leaves remain green. The seedling dies as the water supply is cut off by the decaying tissues. On the leaves and petioles the disease appears as small discolored areas, at first brown, then turning black. On the petiole these spots frequently extend into the vascular tissues, causing the entire leaf to wilt and die. On second-year plants grown for seed, the disease appears as spots along the seedstalk and causes a decay of the inflorescence in wet weather. The stalk may decay and umbels wither before setting seed, or the fungus may actually invade the seed. On diseased roots and stems exposed to high humidity, the mycelium gives the spots a greenish cast with numerous black conidia. In storage, invasion by black rot often opens the way for rapid decay-producing organisms such as
Botrytis cinerea Pers. ex Fr. and Sclerotinia sclerotiorum (Lib.) d'By.

**Disease Cycle.**—Stemphylium persists as conidia in crop refuse and is commonly seedborne (up to 40 percent). Since it is spread to new areas by infested seeds, seed treatment is an imperative control measure. Primary infection may be through the foliage or directly from the soil into the roots. Roots can become infected from diseased tops, from surface contamination during harvest operations, or from contamination in storage maintained above 92-percent relative humidity. In storage, spores and the vegetative mycelium may spread from one carrot to another. The pathogen requires higher than 92-percent relative humidity for rapid development. Infection occurs at 31° to 93° F. with the optimum at 82°.

**Control.**—Measures suggested for control of alternaria and cercospora blights also apply to black rot. Fungicide sprays with carbamates help reduce foliage infection. During harvest use extreme care to lessen bruising and wounding of the roots as well as prolonged exposure to sunlight. Maintain storage at the lowest relative humidity compatible with shrink hazards, preferably below 92 percent. Keep temperatures as near 32° F. as possible. Do not store roots for more than 3 or 4 months.

**Bacterial Soft Rot**

Bacterial soft rot is caused by Erwinia carotovora (L. R. Jones) Holland and E. atroseptica (van Hall) Jennison. It was formerly a much more serious disease when carrots were marketed with tops and without adequate temperature control. These organisms often caused decay of the foliage, and soft rot would spread to the roots. The disease appears infrequently in the field, although infection may occur there and later develop in shipping or in common storage if temperatures rise above 40° F. Decay usually develops first in the crown area and proceeds rapidly down the core. Lesions are grayish to brown with a water-soaked appearance. These tissues soon become slimy and have a putrid odor.

**Disease Cycle.**—The causal bacteria can overwinter in soil where infected crops have grown. Although E. carotovora is a wound parasite, this presents no problem in entering carrots. Harvest bruises, freezing injury, fungus invasion, and especially insect wounds offer good invasion avenues.

Several species of maggot flies, especially Hylemya platura (Meigen) and H. brassicae (Bouché), may actually carry the bacteria in their intestinal tracts. When they lay eggs near or on the plants, the larvae emerge and become contaminated with the soft rot bacteria. As the larvae bore into carrot roots, they introduce the bacteria into the host tissues. There the bacteria multiply rapidly, form in groups between the cells, and
dissolve the pectin of the middle lamella with an enzyme, protopectinase, which they elaborate. This enzyme moves ahead of the bacteria, loosening the cells from one another. Byproducts of the bacterial growth cause the cell contents to flow into the intercellular spaces, where they serve as food for the bacteria. Such cell collapse results in the typical watery or slimy-type decay.

Control.—Since the causal bacteria are generally present wherever susceptible plants are grown, control is based on careful handling at harvest to minimize bruising the carrot roots and on temperature and humidity control during storage. If carrots are washed before storage or shipment, drying in warm forced air should be considered. A storage temperature just above freezing (32°F) and a relative humidity below 90 percent will do much to reduce losses from soft rot. Rotations with carrots following corn, small grains, grasses, alfalfa, or clover are a good practice because such rotations reduce the numbers of bacteria from preceding crops.

**Watery Soft Rot or Cottony Soft Rot**

The fungus *Sclerotinia sclerotiorum* (Lib.) d By. causing watery or cottony soft rot is widely distributed in vegetable soils, because this species has an extremely wide host range, including most vegetable crops. Many flowers, shrubs, and weeds are also attacked. At least eight species of *Sclerotinia* have been reported as capable of rotting carrots; however, *S. sclerotiorum* is by far the most important.

This disease was first reported on carrots in Belgium in 1860 and since then it has been found in every temperate and subtropical region of the world. Its occurrence in storage is dependent on the presence of the fungus in the field previous to and during harvest. Cool, rainy weather is favorable for disease development. Carrots stored wet or subject to "sweating" in storage will decay rapidly.

Lesions caused by the fungus will always exhibit the characteristic cottony snow-white mycelium on the surface of the carrot (fig. 18). In advanced stages of decay, small, black, hard bodies called sclerotia are formed and embedded in the white mold growth. The decay is typically a soft watery rot, but it is distinguished from bacterial soft rot by the absence of sliminess. The decayed tissues are slightly darker than healthy tissues. Secondary bacteria, however, may follow *Sclerotinia* and turn the tissue into a soft, mushy, slimy mass.

*S. sclerotiorum*, although primarily important on roots in storage, can be destructive on carrots grown for seed. The probable cause is infection through wounds produced during transportation of seedlings.
Control.—Rotations should be lengthy and free of the common host plants of *Sclerotinia*. Carrots from fields showing some disease at harvest should be carefully sorted and marketed within 20 days. Maintain storage as near 32° F. as possible and relative humidity at about 85 percent. Avoid condensation of moisture on the carrots by carefully manipulating the temperature and ventilation.

Gray-Mold Rot

The fungus *Botrytis cinerea* Pers. ex Fr., which causes gray-mold rot, is distributed worldwide. It commonly causes rotting in carrots stored more than 3 months at 38° to 42° F. Losses may vary from a trace to 2.25 percent (22). The organism spreads readily in storage, either vegetatively or from one carrot to another by airborne conidia. Rader (22) reported 72 percent of the spore population in carrot storage in New York State to be botrytis. It also invades lesions caused by other fungi.

Lesions may occur anywhere on the root, although most commonly on the crown or tip. The infected tissues are light brown and water soaked at first. The affected areas later appear slightly spongy. Since the diseased cells do not separate, the tissues become leathery in advanced stages of decay. The surface of the spots becomes covered with grayish-brown conidiophores and conidia and under long storage may be accompanied by blackish sclerotia bodies imbedded in the brownish mass (fig. 19). The rot may “nest” in storage.

Botrytis is easily isolated from the soil. It is believed that the organism growing in debris in the soil constitutes the principal source of primary inoculum. With its wide host range, including most commonly grown vegetables, overwintering sclerotia also serve as primary inoculum. Infection may occur in the field during cold, wet weather and be carried into storage. Healthy roots can be stored and later become surface contaminated and then rot depending on temperature and humidity conditions.

Control.—Care in harvesting and handling carrots to reduce injury will minimize infection points on the roots. Regulating temperature and humidity is the principal means of controlling this rot. At 32° F. gray-mold rot develops very slowly. Low humidity tends to check the disease. If humidity is lowered sufficiently to check this rot completely, excessive shrinkage of the roots will occur. Prevent all drip from the cooling coils and ceiling. Using forced air to reduce surface films of moisture is advisable.

Crater Rot

Crater rot is due to *Rhizoctonia carotae* Rader. It frequently causes serious losses in storage in New York and Illinois. Rader (22) did extensive work on the pathogen in New York in 1948–52, when it frequently caused storage losses of 4 to 10 percent. The fungus resembles *R. solani* Kuehn, but it is distinct from it in host range. Inoculations into celery, potatoes, beets, parsnips, and rutabaga were negative with *R. carotae*. Its known susceptible range is still limited to carrot roots.

The decay is first evident as small pitted spots with a whitish mold. The pits enlarge into brown sunken craters lined with a white to cream-colored mold. Decayed tissues beneath the surface lesions are light brown, firm, and dry (fig. 20). In storage
with high humidity the fungus spreads rapidly from the crater until entire carrot crates are covered with white cottony mycelium. This stage of crater rot resembles sclerotinia rot but is distinguishable from it by a looser, weftlike mycelium and the absence of sclerotia. During long storage botrytis and sclerotinia may invade old craters on the roots and cause secondary decay.

Crater rot does not appear until carrots have been stored for 1 to 2 months, but once started it progresses rapidly, and in 2 to 3 weeks it may make carrots worthless. The fungus spreads from infected to healthy roots and even to adjacent crates.

Control.—Control measures are the same as for gray-mold rot. Care in harvesting, prompt cooling, maintaining 32° F. with humidity near 75 percent, and avoiding moisture condensation on the roots are effective control measures.

Woolly Soft Rot

This disease of carrots is caused by *Rhizopus* spp. It occurs only in transit, retail stores, or common storage under inadequately low temperatures (above 40° F.). Several species of *Rhizopus* have been reported associated with this disease symptom. They include *R. arrhizus* A. Fisch, *R. tritici* K. Saito, *R. stolonifer* (Ehr. ex Fr.) Lind, and *R. oryzae* Went & Prin.-Geerl. These fungi are common soil inhabitants, widely distributed throughout the world. When carrots grown in the Eastern United States are placed unwashed in a moist chamber at 81° to 87°, woolly soft rot will develop along with bacterial soft rot, but if they are kept below 40°, no rhizopus fungi will appear.

The decay may begin anywhere on the roots, although the crown and mechanical injuries to the root constitute the most common entry points for the pathogen. The spots have a brownish water-soaked appearance and the decaying tissues are soft and watery but firmer than the rot caused by bacterial soft rot. Hyphal threads can be seen in the tissues and later these will develop the coarse white mycelium or "whiskers" typical of woolly soft rot. This grows over the soft lesions. Since high temperatures favor the rapid development of the fungus, secondary cycles of infection occur, in which the pathogen spreads readily by airborne conidia or by vegetative hyphae growing from one root to another. Infection rarely occurs naturally below 69° F., although it has been produced experimentally at 36°. The optimum is between 87° and 98°.

Control.—Maintain storage temperatures below 40° F. Use adequate ventilation in common storage plus good sanitation measures to keep this disease to a minimum.

Fusarium Dry Rot

This dry rot is caused by *Fusarium roseum* Lk. ex Fr. emend. Snyder & Hansen. The fungus has been found on at least 150 susceptible species of crops. On carrots it produces a crown rot or cankers on the sides of the roots (fig. 21). Symptoms are easily confused with those due to *Rhizoctonia carotae*, and tissues frequently must be examined microscopically to distinguish between these two fungi. Affected tissues under the side cankers are only slightly discolored, dry, and punky. Later upon drying, the cankers become mummified. Decay from crown infections may move rapidly and involve the entire root. Side or crown lesions are often invaded by secondary fungi, which then mask the characteristic symptoms just described. Reddish lesions are infrequently found in carrots kept at a high humidity and 50° F.
Infection probably occurs in the field at harvest or shortly after the roots are stored; however, the disease seldom appears until after several months in cold storage. In warm storage it may become evident after 2 or 3 weeks. The fungus has been carried on seed produced in both Europe and the United States. Seedborne infection provides an effective method of spreading this pathogen to new areas.

**Control.**—To check this fungus, minimize harvest injuries. Also, maintain storage temperature at 31° to 34° F. and keep root surfaces dry and humidity low by means of ventilation.

**Licorice Rot**

Rader (22) in his extensive studies of diseases in stored carrots in New York State found *Centrospora acerina* (Hartig) Newhall to be one of the major causes of storage rot. He first reported it on carrots in New York in 1945, although it had been known in Denmark, Germany, and France since 1900. The fungus attacks many plant species. It causes licorice rot.

Lesions of this disease may occur anywhere on the root. Tissues are water soaked and brownish at first but soon turn a charcoal black. The advancing margin of the lesion always retains a brownish water-soaked appearance. This distinguishes it from black rot, which has a discrete black margin. Under high humidity licorice rot is soft and watery; under drier conditions a less moist, punky rot develops. Infection can occur through intact epidermis when moisture condensation is present.

The fungus can live in the soil for at least 10 months in New York and be reisolated from the soil. Infection may occur anytime during carrot growth and typical symptoms may not show until harvest.

**Control.**—Maintain storage temperatures near 32° F. and relative humidity at 90 percent to reduce spread in storage. Avoid celery in the rotation and
Minor Rots

Several fungi cause minor carrot rots under specific geographical, climatic, and harvesting conditions. In isolated instances one or more of these fungi may flare up to cause serious economic loss. However, with the tremendous advances in harvesting, storing, and transportation technology, most of these rots are of mycological interest only.

Virus Diseases

Aster Yellows

Aster yellows causes severe losses in yield and quality. This disease has been much studied because of its intricate involvement with insect vectors. The first symptom is yellowing of young leaves at the center of the crown. Later a mass of adventitious chlorotic shoots develops and gives a witches'-broom effect (fig. 22). The petioles of the older leaves become twisted and eventually break off. As a result, mechanical harvesting is difficult. In midseason and late season, bronzing and reddening of the tops occur. The bushy tops predispose the roots to various soft rots, which cause decay in the field and in storage. Yellows lowers yield by reducing the size of the root and stands if infection occurs early. Quality is reduced because of numerous woolly secondary roots and a woodiness or toughness with off-flavor and poor color of the carrots.

The disease was first described in asters in 1902, but it was not until 1924 that its cause was reported to be a virus transmitted by the six-spotted leafhopper (Macrosteles fascifrons (Stål)). The disease could be transmitted by grafting but not by other mechanical means. In 1929 yellows disease of carrot was first reported to be caused by the aster yellows virus. M. fascifrons was found to be the chief vector of the western strain of the virus, which is also transmitted by at least 16 other species of leafhoppers. No vector other than M. fascifrons is reported from the Northeast and Midwest.

Japanese investigators and Karl Maramorosch at the Boyce Thompson Institute indicated that a possible mycoplasma is the cause of carrot yellows disease as well as numerous other yellows-inducing diseases. They found various structures resembling mycoplasma, or l-forms of bacteria, or even psittacosis-like agents of animals in the sieve cells, sieve tubes, and companion cells of yellows plants. Maramorosch has since found similar bodies present in leafhopper vectors.

Other investigators showed that by dipping roots of yellows-infected asters in 1,000 p.p.m. of Aureomycin and spraying the leaves every 3 days with the solution, the plants recovered and appeared healthy. However, when sprays were stopped, the symptoms reappeared. These results are consistent with the theory that mycoplasma

Primitive bacteria, which are among the simplest forms capable of independent life.
rather than virus is the inciting agent of the disease. This new theory, if eventually proved correct, is of academic interest but will not change the basic control measures of destroying leafhoppers and eliminating weed and ornamental reservoirs.

Disease Cycle and Vector Relationships.—Two strains of the organism occur. The strain west of the Rocky Mountains is infectious to celery as well as carrot, whereas the eastern or New York strain affects only carrots. Both are dependent on leafhoppers for dissemination and entry into the carrot host plant. A thorough study of the vector-organism-host relationships established that 10 days or more must elapse before either the nymph or adult leafhoppers are able to transmit the disease. Afterward they are infective for at least 100 days. Although the disease agent is not transmitted mechanically from plant to plant, it can be mechanically transferred from one insect to another, but it is unlikely this occurs in nature.

A lapse of 11 to 45 days before disease-infected insects can inoculate plants implies that multiplication of the organism takes place in the insect. When infective leafhoppers were exposed for several days to 31°C (88°F), many permanently lost their ability to transmit yellows but some regained it later. If exposed to heat for at least 12 days, the leafhoppers were permanently unable to transmit the disease agent. This finding suggests that the effect of summer heat on the vectors is responsible for the decline in transmission during warm weather.

The disease organism overwinters in the bodies of adult leafhoppers or in perennial host plants such as weeds and ornamentals. It cannot overwinter in leafhopper eggs. In the Northern States, since these insects overwinter in the egg stage, the perennial host reservoirs are the principal source of infection each spring. They represent more than 40 plant families, including florist crops, weeds, and many vegetables.

Most of the infected hosts in the spring have a peculiar upright growth habit, some distortion in the older leaves, and a yellowish bushy top growth. The time of appearance of the disease in carrots is directly correlated with the flights of leafhoppers from diseased plant reservoirs to young carrots. Incubation requires 10 to 40 days in the carrot with an average of 21 days from inoculation to the first symptom.

Control.—Successful control of yellows involves insecticide control of the leafhopper vectors and removal of overwintering weed and ornamental host reservoirs along roadways, ditchbanks, and fence rows. The vectors prefer to hibernate on barley, wheat, rye, and native grasses and move from these to carrot fields.

Insecticides, including carbaryl and malathion, are commonly used to control yellows by killing most of the vectors. Degrees of tolerance do exist between carrot varieties, but when inoculum potential is high because of abundant leafhoppers, such tolerance is not adequate to protect the crop. Generally Chantenay and Nantes are somewhat tolerant in normal seasons.

Motley Dwarf Disease

Until recently this virus disease was thought to be limited to England, Australia, and Tasmania; however, California and more recently Oregon workers have reported sporadic losses attributed to it. Infected carrots have a stunted, unthrifty appearance resembling certain mineral deficiencies. The foliage develops an irregular chlorotic mottle, with marginal reddening of the lower leaves. Leaflets are distorted and small. Petioles and subpetioles are twisted longitudinally, and the plants are severely stunted. Necrosis may develop on the youngest leaves of fully grown, recently infected leaves and on the older leaves when infection is of long duration. Although top symptoms resemble those of aster yellows, the root system is not malformed and hairy as in aster yellows. Early infection produces heavy losses in yield.

Two viruses are involved in the disease, carrot mottle virus (CMV) and carrot red leaf virus (RLV). CMV can be manually inoculated into other Umbelliferae, Solanaceae, Leguminosae, and Chenopodiaceae, but not into carrot. The host range of RLV is limited to the carrot family and is not manually transmitted. However, it can be transmitted by grafting. Cavariella aegopodiae (Scopoli) aphids transmit RLV alone, but they can transmit CMV only from plants infected with both viruses. The aphids remain infected with both viruses for 7 to 14 days with no evidence of a latent period. Infection is retained through the molt. This is the only aphid species that can transmit the viruses. They are common on carrots, fennel, willow, celery, parsley, and parsnips.
This disease is especially severe in seed carrots, causing high mortality among transplanted seedlings and greatly reducing seed yield from the weakened roots. Control includes delay in planting until aphid populations are reduced, using insecticides, and eliminating wild carrots from the vicinity of commercial fields.

**Controlling Field and Storage Diseases**

Since many diseases originate in the field, successful control includes utilizing several practices throughout the growing season as well as in transit and storage. Only by evaluating and using most or all of these practices can carrot growers achieve economic control of the diseases that damage the crop.

**Rotation**

Since the serious diseases of watery or cottony soft rot (*Sclerotinia*), gray-mold rot (*Botrytis*), and crater rot (*Rhizoctonia*) frequently originate in the field from heldover inoculum, carrots should not follow crops that are subject to these same fungus diseases, i.e., beans, carrots, lettuce, celery, cabbage, cauliflower, or tomatoes. Instead, carrots should follow cereals, onions, alfalfa, clover, spinach, or corn.

**Planting Location**

Carrots should be grown in soil with excellent water drainage and in a location with good air drainage. Carrots grown in wet soil tend to develop enlarged lenticels. Also, the water-loving fungi *Pythium*, *Phytophthora*, and *Botrytis* develop best in water-soaked carrots. Foliage that remains wet with rain or dew for long periods because of poor ventilation is prone to the leaf spot diseases *cercospora* and *alternaria* blight.

**Insecticides and Fungicides**

Early and efficient control of the leafhopper vectors of aster yellows with insecticides is necessary. Timing and coverage are critical for success. In wet seasons or in locations subject to leaf spot diseases, adding a good fungicide to the late July sprays is advisable and should be continued with or without insecticide every 10 days until harvest. Late-season application of fungicides will reduce the amount of inoculum on carrots to be stored.

**Harvesting Procedures**

Proper timing, weather conditions, and minimal bruising must be considered when harvesting carrots. Do not harvest until the soil temperature at the 3-inch level is 50° F. or below. Protect carrots from rain and move them into storage as soon as possible. Use care in digging to avoid bruising, injury, and breakage. This means good padding on the chains, belts, and chutes. Trimming should be done as carrots come out of storage rather than as they go into storage. In case of storage rots, disinfect the roots as they go into storage by dipping them in a 0.1-percent aqueous solution of sodium orthophenylphenate and allow them to drain.

**Controlling Storage Temperature and Relative Humidity**

Lower the temperature of carrots to 32° F. as soon as possible after harvest. Since they generate heat by their own respiration and are 3° to 5° warmer internally than externally, they will not freeze and growth of fungus organisms will be retarded at 32°. Avoid temperature fluctuations when reducing condensation.

Controlling humidity is related to condensation or formation of a surface water film, an excellent medium for spore germination. A relative humidity of 90 percent will prevent water condensation on carrots and still cause only minimal shrinkage.

---

**INSECTS AND THEIR CONTROL**

Although carrots are attacked by many insect and mite pests, only a few are of major economic importance.

**Wireworms**

Wireworms are the yellowish cylindrical larvae of click beetles (family Elateridae). They damage carrots by tunneling into the roots and causing unsightly blemishes (fig. 23). As the roots enlarge, the burrowings may cause splitting of the carrots. Since most species of wireworms take more than a year to develop, larvae are frequently present when the carrots are planted. Species of economic sig-
Figure 23.—Typical injury to carrots by wireworms.

Figure 24.—Oregon wireworm (side and top view). × 2.

Significance include the sugar-beet wireworm (*Limonius californicus* (Mannerheim)), the Oregon wireworm (*Melanotus oregonensis* (LeConte)) (fig. 24), and the southern potato wireworm (*Conoderus fallii* Lane). Control consists of soil treatment with diazinon.

**Carrot Rust Fly**

Maggots of the carrot rust fly (*Psila rosae* (F.)) damage carrots in some areas. The yellowish-white maggots, one-third inch long, destroy the fibrous roots and tunnel into the fleshy taproot. In severe attacks the entire root is riddled with burrows and the carrots become unmarketable. Control consists of treating the seed furrow with granular diazinon at time of planting.

**Vegetable Weevils**

Larvae of the carrot weevil (*Listronotus oregonensis* (LeConte)) (fig. 25) start feeding by tunneling into the leaf petioles, where they enclose the short stem, and then tunnel to the roots, where they make unsightly blemishes. The vegetable weevil (*Listroderes costirostris obliquus* (Klug)) is an
occasional pest, usually around the edge of carrot fields where the infestation often spreads from weeds (particularly *Malva* spp.) to carrots. The cream-colored larvae feed on the stems, foliage, or roots. Weevils can be controlled with parathion.

**Carrot Beetle**

Both larvae and adults of the carrot beetle (*Bothynus gibbosus* (De Geer)) (fig. 26) feed on carrot roots. These robust insects of the June beetle type are one-half to five-eighths inch long and are a uniform reddish brown. The whitish larvae or grubs feed on roots and the adults on both roots and tops. Damage often occurs on new land where weeds and native vegetation have been grubbed out prior to planting. Clean farming practices and crop rotation often avert serious attacks of this beetle.

**Western Parsley Caterpillar**

A western parsley caterpillar, *Papilo selicaon* Lucas, often occurs on carrots and related members of the family Umbelliferae. Green, black, and orange caterpillars of this handsome swallow-tailed butterfly feed on the foliage. Normally no control is necessary.

**Cutworms and Armyworms**

Many species of cutworms and armyworms damage carrots by cutting off the young plants at the soil surface or by feeding on the stems, foliage, or roots. Usually cutworms are present at the time of planting and immediately attack the young seedlings. The black cutworm (*Agrotis ipsilon* (Hufnagel)) is primarily a soil-inhabiting species. It feeds at night on the foliage of young plants and severs the root. Most of the armyworms work above ground and feed on the rosette leaves of the young plants. Control consists of applying an insecticide such as carbaryl.

**Six-Spotted Leafhopper**

The six-spotted leafhopper (*Macrosteles fascifrons* (Stål)) transmits aster yellows to carrots. In
some areas 35- to 50-percent loss from aster yellows may occur. Many other species of leafhoppers also feed on carrot, and about 16 species can transmit the western strain of this disease. Carbaryl, malathion, or methoxychlor will control this insect.

**Loopers**

Larvae of the cabbage looper (*Trichoplusia ni* (Hübner)) and the celery looper (*Anagrapha falcifera* (Kirby)) occasionally attack carrots. These green caterpillars are semi-loopers belonging to the family Noctuidae. They feed on the above-ground parts of plants, pupating in flimsy silken cocoons on the plants. In the Southern States they are often most destructive to seedlings.

**May Beetle**

Adults of a wingless May beetle, *Phyllophaga cribrosa* (LeConte), are destructive to carrots in Texas, where they migrate from uncultivated to cultivated areas. In September and October entire plantings of seedlings may be destroyed. Control consists of using trap furrows around the field.

**Occasional Pests**

A celery rust mite, *Aculus eurynotus* (Nalepa), which causes a russetting of leaves and stems, and a celery and carrot bud mite, *Aceria peucedani* (Canestrini), occur on carrots in California. The clover mite (*Bryobia pratiosa* Koch) may infest carrots during the winter and the two-spotted spider mite (*Tetranychus urticae* Koch) is also an occasional pest. The spinach crown mite (*Tyrophagus diminutus* (Hermann)) often enters cracks in carrots in addition to attacking healthy tissue, where it breaks down root tissues and thus allows entrance of secondary rot organisms. Since this mite also breeds on carrots left in the field, it is a potential threat to a subsequent spinach crop.

Several aphids are associated with carrots. One of the commonest is *Cavariella aegopodii* (Scopoli). It is a vector of carrot motley dwarf virus. Eleven species of aphids are involved in transmitting western celery mosaic virus. The melon or cotton aphid (*Aphis gossypii* Glover) spreads southern celery mosaic virus from weeds to carrots in certain areas. An aphid, *Dysaphis apiifolia* (Theobald), in specific locations in California infests the crowns and roots of carrot.

Blister beetles of the genus *Epicauta*, particularly *E. murina* (LeConte), often attack carrot foliage. Grasshoppers may be occasional pests. Several maggots, including the seed-corn maggot (*Hylemya platura* (Meigen)) and the cabbage maggot (*H. brassicae* (Bouché)), occasionally damage carrot roots, permitting entrance of bacterial soft rot.

**NEMATODES AND THEIR CONTROL**

Throughout the world several plant-parasitic nematodes attack and damage carrots. In the United States, however, the most important nematode disease of carrots is caused by root-knot nematodes. Since several species of this nematode damage carrots, it is important to know which species is present when a rotation program is planned to control the pest.

**Root-Knot Nematode**

The root-knot nematode (*Meloidogyne* spp.) is a microscopic, plant-parasitic roundworm found in soil in many areas of the country. It must feed on the roots of a susceptible plant, such as carrot, to complete its life cycle and to reproduce. The second-instar larva is infective and, with the exception of the male, is the only motile stage in the life cycle of this nematode. Therefore only the larvae, some eggs, and occasionally males occur in the soil. The remainder of the life cycle is spent inside the root. After the larvae penetrate the roots, they become sedentary, feed, and reach sexual maturity. An adult female may produce 500 eggs or more, and the life cycle can be completed in less than 1 month under optimum soil-moisture and temperature conditions. Adult females deposit their eggs in masses within the root tissues or protruding into the soil.

Optimum moisture for root-knot nematode growth is a soil-water level near field capacity, and an optimum soil temperature is between 78° and 85° F. Even though only a few eggs or larvae are present in the soil at the time of planting, the re-
productive potential of this nematode is so high that nematodes can be produced within a month or two in such numbers as to severely damage a carrot root.

In the absence of host plants, some second-stage larvae or eggs may survive in soil for several years if moisture is present. After this period if a desirable host such as carrot is planted, the second-stage larvae can penetrate the roots and develop to maturity, reproduce, and possibly damage the carrot root. One species of root-knot nematode, Meloidogyne hapla Chitwood, can survive over prolonged periods in frozen soil.

**Symptoms.**—The aboveground symptoms of root-knot nematode damage to carrot are similar to those caused by many other root disorders. Infected plants are unthrifty and display various degrees of chlorosis and stunting depending on the severity of attack and the time of infection. Root-knot damage in the field is often found in irregular "pockets" or spots, which range from a few feet in diameter to several acres. It is usually most severe in the coarser textured soils such as loamy sands and sandy loams.

The diagnostic symptom of root-knot nematode damage to carrot occurs on the roots. When plants are dug with a shovel and the soil gently removed, galls of varying sizes are evident on the taproot and fine lateral roots. Heavily infested roots not only are unsightly but are a total loss if damage to the taproot is severe. The taproot itself may be growing at various angles depending on the time and severity of infection. When young seedlings are attacked, a loss of stand may result.

By closely examining infected roots, egg masses usually can be seen protruding from the galls. These are white to yellow brown and are one-half to 1 mm. in diameter. The glistening white adult female, the size of a pinhead, can often be seen when the root tissue directly under the egg mass is gently removed with a sharp knife. Roots severely infected with root-knot nematodes are often completely decomposed by secondary invading organisms such as fungi or bacteria.

**Control.**—Controlling root-knot nematode disease, as well as other potential nematode diseases, can be accomplished by various means, including quarantine, resistant varieties, cultural practices, and chemicals.

Quarantine measures are enforced by Federal, State, and county agencies. These measures aid in protecting growers from the introduction of known nematode pests into uninfested areas. Growers can impose quarantine or sanitation procedures upon themselves to help prevent the spread of nematodes on their own property. Examples of this would be to avoid planting nematode-infested rootstocks on their land or moving nematode-infested soil on machinery or other equipment from infested to clean fields.

No commercial carrot varieties have root-knot nematode resistance. However, breeding programs are being conducted with nematode resistance as an objective.

Such cultural practices as dry fallow and rotation with resistant crops can be as effective as chemical treatments for root-knot control on carrots. The combination of fallow during nonproductive winter months in the colder parts of the United States, followed by growing a resistant crop the following summer, usually reduces the nematode population to a level low enough that a carrot crop relatively free from nematode damage can be grown the second year. Growers should make sure to control weed hosts in fallow and rotation programs if these programs are to be effective. Growers should also consider the potentially reduced profits from their land if fallow or rotation control programs are used. As an example, it is sometimes more profitable for a grower to utilize chemical control measures annually and grow a susceptible crop like carrots because of the greater income per acre of carrots over a resistant host such as grain.

For preplant nematode control on carrots, fumigants can be applied either broadcast or in row applications. The method the grower chooses will depend on specific conditions in the growing area. Broadcast applications generally will assure better control, since carrot row spacings are relatively close and the savings in amount of nematicide applied by row treatments would be rather small.

Several fumigants for preplant nematode control are available. They are marketed under various trade names by several companies. Their active ingredients are ethylene dibromide, 1,3-dichloropropene (D-D mixture, Videlien-D, Telone), and 1,2-dibromo-3-chloropropane (Nemagon, Fumazone).
For postplant nematode control on carrots, only one fumigant is currently registered and recommended in some States. This material is DBCP (1,2-dibromo-3-chloropropane). Even though it can be used as a postplant nematicide, growers would be better off to utilize preplant control procedures for the following reasons: (1) DBCP is not systemic in action and will not kill nematodes that have already entered the carrot roots at time of treatment, and (2) relatively little root-knot nematode damage to the carrot taproot is required to make it nonmarketable.

Fumigation for nematode control is most efficient when the following factors are carefully considered:

1. **Seedbed preparation.**—The soil in the seedbed should be well prepared and free of large clods and undecomposed plant debris. If plow soles or severe compaction exists, the earth should be subsoiled and the seedbed in good tilth for maximum fumigation efficiency.

2. **Soil moisture.**—Soil moisture at time of fumigation must be at the highest level to permit effective land preparation. In lighter soils this is usually at or near field capacity and in heavier soils this may be slightly below field capacity.

3. **Soil temperature.**—Soil temperature is a critical factor. Between 45° and 85° F. is usually adequate. However, at the lower temperature the time between fumigation and planting must be lengthened because of the potential toxicity of fumigant remaining in the soil.

4. **Organic content.**—The soil at time of fumigation should be relatively free of undecomposed plant residues, which absorb or adsorb the fumigant and lessen its effectiveness. Also, these undecomposed residues protect endoparasitic nematodes from exposure to the fumigant.

5. **Sealing soil surface.**—The soil should be compacted with a ring roller or cultipacker to seal its surface immediately after the fumigant is injected. Repeat the treatment at least twice. If this equipment is not available, spike-tooth or spring-tooth drags can be used. However, they are not so efficient as the cultipacking equipment for closing the soil surface.

### Other Nematodes

Other nematodes infesting soils where carrots might be grown are as follows:

<table>
<thead>
<tr>
<th>Genus</th>
<th>Common name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belonolaimus</td>
<td>Sting nematode</td>
</tr>
<tr>
<td>Hemicyclophora</td>
<td>Sheath nematode</td>
</tr>
<tr>
<td>Longidorus</td>
<td>Needle nematode</td>
</tr>
<tr>
<td>Nacobbus</td>
<td>False root-knot nematode</td>
</tr>
<tr>
<td>Paratylenchus</td>
<td>Pin nematode</td>
</tr>
<tr>
<td>Pratylenchus</td>
<td>Lesion nematode</td>
</tr>
<tr>
<td>Rotylenchulus</td>
<td>Reniform nematode</td>
</tr>
<tr>
<td>Trichodorus</td>
<td>Stubby root nematode</td>
</tr>
</tbody>
</table>

In certain isolated areas these nematodes are known or believed to damage carrot. Not enough information is available to recommend control measures. It is suggested that growers with large populations of one or a combination of these nematodes in carrot fields apply preplant fumigants recommended in their area to a small section of the field and observe the results.

### SELECTED REFERENCES


